COOPERATIVE INSTITUTE FOR LIMNOLOGY AND ECOSYSTEMS RESEARCH (CILER)

ANNUAL REPORT

NA17RJ1225 — Year Two
July 1, 2002 to June 30, 2003

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The Cooperative Institute for Limnology and Ecosystems Research (CILER), was established in 1989, and is the only joint institute with direct responsibilities for research in fresh water. CILER activities are not, however, limited to the limnetic environment; they also support research in estuarine and coastal marine environments. CILER research is focused in five areas: climate and large-lake dynamics, coastal and nearshore processes, large-lake ecosystem structure and function, remote sensing of large lake and coastal ocean dynamics, and marine environmental engineering.

CILER is a joint endeavor of the University of Michigan, Michigan State University, and the NOAA/Great Lakes Environmental Research Laboratory (GLERL). Its administrative offices are located at the University of Michigan in Ann Arbor. CILER promotes collaborative research between GLERL and scientists from throughout the Great Lakes Basin. Currently, CILER has more than 70 collaborators who represent almost every phase of limnological research. The Council of Fellows – which is composed of individuals from GLERL, the University of Michigan, and representatives from universities throughout the Great Lakes Basin – provides the primary intellectual guidance. In addition, CILER continues to support post-doctoral research fellows on various projects as well as a number of students including secondary, undergraduate and graduate students. Accomplishments for projects supported during the past year follow.

Summary of Joint Institute Staff by Head Count FY01

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	2			2
Visiting Scientists	0			
Postdoctoral Research Fellows	2			2
Research Support Staff	16	10	6	
Administrative	3	1	1	
High School Students	6			
Undergraduate Students	10			
Graduate Students	10			
Totals	49	11	7	4

Summary of Joint Institute Staff by Head Count FY02

Category	Number	B.S.	M.S.	Ph.D.
Research Scientists	1			1
Visiting Scientists	0			
Postdoctoral Research Fellows	1			1
Research Support Staff	14	7	6	
Administrative	3	1	1	
High School Students	3			
Undergraduate Students	15			
Graduate Students	6			
Totals	43	8	7	2

Research Overview

This report details activities for the second year of our current cooperative agreement and covers the period from July 1, 2002 to June 30, 2003. During this period CILER administered 31 projects within our five research themes plus our Task I visiting fellows and science enhancement program. Twenty-four of these projects are continuations of research projects funded in the past fiscal year and seven of the projects are new in this fiscal year.

The research funding level for this year's cooperative agreement activity was $1.27 million. Funding levels have remained fairly consistent over the past three years, averaging about $1.25 million per year, but are slightly down from the years 1996 – 1998, where average funding reached $2.3 million per year. In addition, CILER has sponsored approximately $1.23 million of research activity external to the cooperative agreement during this reporting period. These external funds are from non-NOAA agencies, but activities conducted within these projects still meet our overall research mission and frequently involve participation by NOAA investigators. External sponsors include the Great Lakes Protection Fund, the Michigan Great Lakes Protection Fund, the Great Lakes Fishery Trust, the Great Lakes Fishery Commission, the Albert P. Sloan Foundation, the Academy of Natural Sciences, and the Consortium for Oceanographic Research and Education. Lastly, one National Sea Grant award was done as a subcontract to Old Dominion University and came directly through the University of Michigan.

Six of the projects within Task I represent continuing research activities that were initiated last year as part of our science enhancement program. Science enhancement projects were awarded through a special call for proposals that establish research collaborations between Great Lakes basin faculty and NOAA scientists at the Great Lakes Environmental Research Laboratory. The program was supported by funds through the Office of Oceanic and Atmospheric Research. This program has been very successful in establishing new research collaborations at various institutions throughout the basin and has greatly supported our overall mission. Unfortunately, funds were not available to offer a new call for proposals in this fiscal year.

Other research activities that were conducted under Task I include our postdoctoral fellows program, our summer high school intern program, our Great Lakes Student Summer Fellows program for undergraduates and graduates, a Great Lakes seminar series run in collaboration with NOAA-GLERL, and a research workshop co-hosted with NOAA-GLERL on behalf of the Coastal Ocean Program.

We currently have active research projects in all five of our thematic areas; however, our themes pertaining to coastal processes and ecosystem dynamics continue to be a major focus for CILER. The two projects in our climate and large-lake dynamics theme represent ongoing, multi-year programs. The first project pertains to hydrodynamics modeling activities conducted under a five-year study on the impact of episodic events on nearshore-offshore transport in the Great Lakes (EEGLE). Although the EEGLE research program is nearing completion, the advances made in our numerical modeling capabilities have been extended into numerous other research activities at CILER and GLERL. The second project in this theme represents an ongoing collaboration between NOAA and the Lake Champlain Research Consortium to investigate hydrodynamic processes of Lake Champlain and its surrounding watershed.

There were three active projects within our coastal and nearshore processes theme area. Two of the projects were associated with the EEGLE program and were focused on the importance of episodically driven fluxes of material on pelagic productivity in southern Lake Michigan. Specifically, one project examined the influence of resuspension events on phosphorus dynamics and heterotrophic production, and the second project examined influences on phytoplankton processes. The third project was conducted under the Lake Champlain program and focused on understanding physical processes driving sediment transport in Shelburne Bay.

The majority of research projects (eight) were related to our ecosystem structure and function theme. Two projects were focused on the impacts of invasive zooplankton on pelagic food webs in Lake Michigan. The attention given to food web disruption by invasive species has increased significantly in the past few years and is a major issue for resource managers throughout the Great Lakes. Two additional proposals focused on disruption of benthic food webs in the Great Lakes. Specifically, these projects examined the impacts of the sudden and unexplained disappearance of *Diporea*, a benthic amphipod that is a major food source for many larval fish species. A fifth project continues a long and productive research program on improving our understanding and assessment of the toxicological effects of bioaccumulating organic contaminants. These contaminants represent a legacy of pollution discharges to the Great Lakes during the heyday of the industrial development within the basin. A sixth project on post-depositional mobility of biochemically important materials focused on completion of laboratory analyses of samples that have been collected for several major research efforts at CILER and GLERL including EEGLE and the Lake Michigan Mass Balance Study. Collectively these programs are providing the most comprehensive suite of chemical inventories, sedimentation rates, and sediment transport dynamics ever assembled within the Great Lakes. These studies are critical because the near surface sediments within the lakes contain huge inventories of important nutrients, as well as, harmful contaminants, and the resuspension and transport of these sediments has profound

effects on the ecology and water quality of the ecosystem. A new, seventh project, was established this year to examine organic compounds that might serve as geochemical proxies to reconstruct paleo-environmental conditions within the Great Lakes. If successful, these approaches may also serve as a valuable research tool for understanding more recent climate change impacts. The eighth project is also a new activity and is focused on improving our understanding of wetland ecosystem function, and in particular at developing improved metrics for assessing the potential impacts of applying wetland restoration practices along coastal margins of the Great Lakes.

We had two continuing projects in our remote sensing and coastal ocean dynamics theme. One project continues the long-term collaboration between CILER and NOAA-GLERL to develop and facilitate research products using remotely sensed data for the Great Lakes. Activities that utilize these data and products are quite diverse and include research on ice cover and ice classification, surface temperatures, turbidity, Great Lakes coastal forecasting, and algal blooms. The second project is a continuation of a NOAA-NGDC research activity lead by a CILER fellow at the University of Michigan. The work focuses on the examination of electric fields in the subauroral ionosphere and near-Earth magnetosphere. These electric fields have a strong influence on space weather, and potential implications on important operational systems such as GPS.

We have continued to see an increased activity in our marine environmental engineering theme, since its inception to our suite of research themes in 1996. The current focus of most of this research is on the assessment and control of aquatic invasive species (AIS) that result from commercial shipping activities within the Great Lakes. Two projects are focused on assessing the potential of using chemical disinfectants onboard ships as a treatment process for controlling invasive species introductions and the risk to native species of discharging such treated ballast. A third project is examining the potential risk associated with ships that declare no-ballast-on-board and are subsequently devoid of any treatment procedures or screening under current federal policies. The remaining project within this theme is focused on developing passive acoustic methods for monitoring the distribution and movements of right whales. This research is sponsored by NOAA-NOS and was conducted under collaboration with experts in acoustical methods affiliated with Cornell University.

Publication Summary by Reporting Period

	JI Lead Author		**NOAA Lead Author**		**Total by FY**	
	FY01	FY02	FY01	FY02	FY01	FY02
Peer-Reviewed	10	16	2	5	12	21
Non Peer-Reviewed	1	7	1	4	2	11
Total by Author	11	23	3	9	14	32

ADMINISTRATION AND RESEARCH ENHANCEMENT

CA4/I-02: PARTNERS-FOR-EXCELLENCE SUMMER HIGH SCHOOL INTERN PROGRAM

Principal Investigator: Thomas F. Nalepa, Great Lakes Environmental Research Laboratory

As part of a partnership with the Science Department of the Ann Arbor Public Schools, the Great Lakes Environmental Research Laboratory and the Cooperative Institute for Limnology and Ecosystems Research sponsored three high school interns to work with a GLERL or CILER mentor for the summer 2003:

Alice Dryden	Pioneer High School	Mentor: Radka Pichlova
Daniel Enter	Huron High School	Mentor: George Leshkevich
Glenn Persello-Seefeld	Pioneer High School	Mentor: Thomas Nalepa

The applicants went through a preliminary selection process by the Ann Arbor Public School system. Each applicant composed an essay that conveyed their interest in the internship and their qualifications, and was recommended by their science teacher. Final selections were made after interviews with GLERL or CILER mentors.

Each intern was assigned a mentor and performed research duties such as laboratory set-up, experiment preparation, data analysis, data coding, and computer input. Each intern summarized his or her experience in an essay for the Partners-For-Excellence Program.

CA4/I-04: DYNAMICS OF LOCALIZED EDGE WAVES IN THE GREAT LAKES

Co-Principal Investigators: David J. Schwab, Great Lakes Environmental Research Laboratory and Junaid As-Salek, University of Michigan

During certain meteorological events, water level oscillations up to 1.5 m with periods of less than 2 hr have been observed in the Great Lakes. The squall line events of 7-11 March 1998, 29 May-2 June 1998 and 8-12 November 1998 in Lake Michigan, were analyzed by spectral and analytical methods. Dominant periods less than 2 hr were identified in the spectra of water level fluctuations, and coherencies among the spectral peaks of water levels of different station pairs were calculated to determine whether the oscillations were localized or basin wide. Explicit numerical calculations of normal mode periods and structures using a Lanczos procedure showed that the dominant periods in the observed data were consistent with the structures and periods of some of the calculated modes. The March 1998 and the November 1998 episodes showed higher surges with a gradual rise of water level, while the episode of May 1998 showed an abrupt rise in the water level at Calumet Harbor and about ten times higher spectral signature than the former two. Many of the high frequency modes had large amplitude at or near Calumet Harbor and the periods were close to the periods of edge waves that would be generated by a squall line similar to the May 1998 squall line. The trapping of energy and localized higher modes in a water body can work together to excite edge waves and localized seiches causing abrupt water level fluctuations.

Publications

As-Salek, J.A. and D.J. Schwab. 2002. High frequency water level fluctuations in Lake Michigan. *ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering* (in press).

Presentations

As-Salek, J.A., D.J. Schwab and D. Beletsky. 2001. Dynamics of high frequency water level fluctuations and storm surges in Lake Michigan. International Conference on Coastal Engineering. September 19-21. Rhodes, Greece.

As-Salek, J.A. 2000. GLERL Distinguished Scientist Seminar Series, November 21. Ann Arbor, Michigan.

As-Salek, J.A. 2000. Initial findings about high frequency fluctuation in Lake Michigan. EEGLE All-Hands Meeting. September. Ann Arbor, Michigan.

Significant Interactions

Dr. Tad Munty, advisor to the World Meteorological Organization and UNESCO and former senior research scientist, Federal Government of Canada; Adam P. Fox, physical scientist, U.S. Army Corps of Engineers, Detroit, Michigan; and Jon Banitt, forecaster, National Weather Service, Marquette, Michigan.

CA4/I-05SE: Investigations into the Decline of the Amphipod Diporeia in Lake Michigan: Changes in Potential Food Using the Sedimentary Record of Diatoms

Co-Principal Investigators: Eugene F. Stoermer, University of Michigan; Thomas F. Nalepa, Great Lakes Environmental Research Laboratory; and John A. Robbins, Great Lakes Environmental Research Laboratory

This project was initiated as a preliminary investigation of the probability that food chain effects, particularly changes in abundance and composition of phytoplankton being deposited into the benthic environment, was a factor in declines of the benthic amphipod *Diporeia* in Lake Michigan. *Diporeia* is a major food source for many fishes in the Great Lakes, and its decline is a matter of concern for fisheries managers and ecologists. Diatoms have often been used to document changes in the environment of lakes, including changes in their biota. They also have direct connection to the production of valued fish, in that they are a major source for the lipid food chain, which is important in boreal lakes. Three major hypotheses were investigated in this study:

- There has been a significant reduction in the total amount of lipid-rich potential food to the benthic community.
- There has been a significant change in the composition of the diatom rain to the benthic community.
- There are significant spatial differences in the amount and/or composition of potential food materials being produced and delivered to benthic communities in Lake Michigan.

On the basis of our results, the first hypothesis appears to require modification. Our results show that there was a significant decrease in diatom deposition from the late 1980s until ca. 1996. After this the concentration of diatom frustules in the sediments investigated increased to levels approximately similar to previous conditions. From this, it may be hypothesized that a reduction in the food base may be at least partially responsible for the observed *Diporeia* decline, but there is a significant time lag between measured response in the primary producer community (diatoms) and measurable effects in the invertebrate community.

Our results quite strongly support the second hypothesis. There is an apparent shift from previously very abundant large centric species to araphid pinnate and small centric diatoms. This is particularly significant because species of *Aulacoseira* can survive for extended periods in sediments (up to centuries), and the diatom spring bloom has been shown to support benthic production throughout the seasons. The species that have replaced spring-blooming *Aulacoseira* have lesser vegetative survival capabilities and probably lesser lipid content. This aspect of the present preliminary study certainly deserves further investigation and elaboration.

The third hypothesis is of interest because of the apparent shift in *Diporeia* abundance over time but was not supported by our results. Of the four cores investigated, only two preserved an adequate record of diatom deposition. The two cores that do contain apparently complete records exhibit only small differences, not beyond the level of probable error to the degree of accuracy allowed by our present enumeration protocol. It is possible that more extended counts could expose north - south differences, but we consider this unlikely. Advective transport, especially during the spring when diatom production is most rapid, probably results in deposition of material from a wide area at any given single site. Higher resolution counts may be useful to expose statistically reliable more records of low-abundance taxa, but discovery of regional differences, except on a broad scale, is unlikely using this technique.

Publications

This project has not yet resulted in any formal publications. Data has been provided to NOAA collaborators, Drs. Thomas Nalepa and John Robbins, in electronic format for their consideration before a decision is reached as to the appropriate strategy for eventual publication. Our original thought was that this work would furnish the basis for a more extended proposal. It now appears that publication of the data developed so far may be justified. Because NOAA collaborators have ownership of the original samples and dating results, it will be necessary to reach general agreement as to the most appropriate strategy.

Significant Interactions

Most potentially significant interactions have been with the EPA STAR project "Great Lakes Environmental Indicators." This is a large, multi-institutional effort that includes a component on diatom communities in the nearshore zone. The results of research described here are pertinent.

CA4/I-06SE: High-Resolution, Two-Way Nested Grid Model of Coupled Large Lake and Nearshore Processes

Co-Principal Investigators: Nik D. Katopodes, University of Michigan and David J. Schwab, Great Lakes Environmental Research Laboratory

The hydrodynamics of the Great Lakes encompasses processes whose spatial and temporal scales differ by several orders of magnitude. Local interaction of waves and currents, contaminant loading at river estuaries and non-point sources, fine sediments from bluff erosion and many similar phenomena affect the state of the entire lake system. Local happenings such as accidental spills, terrorist acts, and pollutants originating in a coastal acquifer can have major consequences for the entire Great Lakes system. However, it is often impossible to detect and monitor such events in a large lake because of the formidable computational effort required. It is possible to do so in specific nearshore regions, but this cannot be done without first determining the hydrodynamics of the whole lake. The transfer of energy from large to small scales is the predominant factor driving the small scale effects, whose local features require that the nearshore processes be resolved as accurately as possible. These features often modify the large-scale hydrodynamic effects and in the case of mass transport, almost always determine the characteristics of the source itself.

Despite advances in computer technology, nesting a high-resolution, limited-area nearshore model within a coarse-grid model covering a large lake is the only viable approach to capturing the details of hydrodynamic phenomena that originate in the nearshore region, but may be of a great importance to the coarsely resolved lake scale. In a nested grid model, the nearshore component is hydrodynamically driven by the lake model, so two-way passage of information is required between the two models, which must be enforced by appropriate boundary conditions and filters. Furthermore, eddy energetics must converge at nest boundaries to satisfy the basic conservation laws. The difficulty in implementing such a scheme is obvious. An eddy that is resolvable in the fine grid may be completely invisible to the coarse grid.

Past attempts to develop nesting approaches have been only partially successful because of the lack of consistent universal conditions at the nest interface. Typical radiation conditions render primitive equation models ill posed and require artificial means for filtering short waves. Forcing at the nest boundary often results in erroneous flow fields because flexes are not normal to the interface, especially when the bathymetry is complicated across the boundary. This results in inaccuracies in both the finely and coarsely resolved solutions and often yields results that are inferior to those of the coarse grid alone.

This project started May 1, 2002. In this short time we have developed a nesting methodology and a computer cluster scheme that will implement it. We are still investigating the message passing interface. We have selected the Muskegon River estuary as our practical application and we currently are developing the computational grid and collecting bathymetric data.

Presentations

Katopodes, N.D. 2002. Contaminant transport by density currents. The 6th International Conference on Protection and Restoration of the Environment. Skiathos, Greece. July.

Katopodes, N.D. 2002. Transboundary transport of groundwater pollutants by lake currents. UCOWR-ERI/ASCE Special Joint Conference. Traverse City, Michigan. July.

Significant Interactions

We had discussions with IBM regarding the possibility of their donating a computer cluster system to our project. Negotiations continue.

CA4/I-07SE: Molecular and Isotopic Paleotemperature Proxies in the Great Lakes Sediments: Keys to Climate Prediction?

Co-Principal Investigators: Philip A. Meyers, University of Michigan and Brian J. Eadie, Great Lakes Environmental Research Laboratory

Rationale

The climate of the Great Lakes region is generally projected to become warmer and wetter over the coming century. However, the extent of these changes is not expected to be uniform – the western part of the region is likely to be warmer and not as wet as the eastern part (Sousounis and Bisanz, 2000). A possible consequence of the regional differences is that lake-levels may be impacted differently. To compound this uncertainty, how the transition to warmer climate will occur is not known. Will it be a gradual change to the new style of climate, or will it be a period of unstable climate until the new regime is established? Important insights into what the future might hold are available by studying past climate changes in the Great Lakes region.

The climate of the mid-Holocene Hypsithermal provides a possible model for the future climate of the Great Lakes region. Thy Hypsithermal was a period of warm and dry climate from about 9 to 5 kybp in much of the Great Plains region (Dean et al, 1996), but it was a time of warm and wet climate in the eastern Great Lakes area (Silliman et al, 1996). From depth of submergence of drowned tree stumps, Blasco (2001) concludes that water levels at about 7.5 kybp in Lake Huron were so low that this lake was isolated. In contrast, stranded beaches around Owasco Lake (one of the New York Finger Lakes) led Dwyer et al (1996) to conclude that water levels were locally elevated at this time. The difference in mid-Holocene water levels may be a harbinger of the possible consequences of future warming in the Great Lakes region.

The transition from the warmer climate of the Hypsithermal to near-modern cooler climate conditions was not smooth in the Great Lakes region. Evidence of dramatic, century-scale oscillations between warm and less-warm conditions between 7 and 5 kybp appears in sediments deposited in Seneca Lake, New York (Meyers, 2002) and in Shingobee Lake, Minnesota (Dean and Schwab, 2002). If this

climate transition was unstable, it is plausible that the opposite transition – one to a warmer climate – could be similarly unstable.

Stable oxygen isotope studies in lakes have been widely used to deduce regional paleoclimatic histories. Many recent studies have focused on the use of oxygen isotopes of both bulk carbonate and of specific organisms to recreate climatic conditions. These reconstructions can take the form of temperature, atmospheric circulation patterns, precipitation to evaporation balance, and lake levels. All of these variables impact lakes and can be studied using stable isotopes. The most common studies involve the usage of oxygen isotopes as a proxy of either air or water paleotemperature. Most studies have addressed long time scales where actual climatic data is limited or unavailable.

Evidence of short-term changes in the near-recent climate of the Great Lakes region is also preserved in sediments. Schelske and Hodell (1991) describe variations in the accumulation rates and $\delta^{18}O$ values of calcite in Lake Ontario sediments that correspond to interannual differences in temperature. They postulate that precipitation of greater amounts of isotopically light calcite accompanied times of longer thermal stratification of Lake Ontario (warmer years). Interestingly, sediments deposited in Lake Ontario during the mid-Holocene Hypsithermal also contain elevated concentrations of calcite (Silliman et al, 1996), perhaps recording a long-lived interlude of longer seasonal stratification during this time of warmer climate. Similar climate variations are likely to appear in the future.

This study investigates the record of oxygen isotopic changes over the last century in Lake Erie, a period for which climatic data are available. The results of this study should provide insight into the factors controlling the isotopic signature in the Great Lakes region and other large lakes in temperate zones. Lake Erie provides an ideal location to investigate the relation between the sedimentalogical and historical records in terms of climatic changes that have occurred over the last hundred years (1895-1991). Lake Erie is a complex system, but has significant advantages relating to its large surface area (25,700km^2), shallow depth (maximum of 64m and average of 19m) and short retention time (2.6 years) which make this lake especially responsive to hydrologic and ecologic changes.

Progress

At the present time, we have analyzed two cores from the eastern basin in Lake Erie where accumulation is approximately 1 cm per year. These cores were collected in 1983 and 1991. The amount of calcium carbonate found in the 60 cm box core ranges from 3.0 percent to 9.7 percent with an average value of 5.4 percent. These data generally fluctuate around the mean value, but there are a series of distinct peaks (1977, 1980, and 1982) and troughs (1964, 1975, 1977, and 1981) that appear throughout the early part of the record. The greatest change however occurs in the late 1980s where the amount of calcium carbonate begins to increase to levels (greater than nine percent) that are not seen in the previous forty years.

The amount of calcium carbonate found in the 1991 Benthos gravity core ranges from 2.5 percent to 10.7 percent with an average value of 6.3 percent. In 1895, the amount of calcium carbonate is around eight percent, which is followed by a sharp decline starting around 1903 that lasts for several years. These values then

slowly return to a baseline of about eight percent (starting in 1913) once again but with some distinct pulses of increased carbonate precipitation before dropping sharply in the mid-1950s. From this point until the mid-1980s, there is only about four percent calcium carbonate present in the sediment. In the mid-1980s the percentage of calcite rises and begins to approach values seen earlier in the century. This trend of increased calcite is clearly seen in both of the cores.

Carbonate $\delta^{18}O$. The oxygen isotopic compositions of $CaCO_3$ from the late 1950s to the early 1990s range from –5.16 percent to –6.03 percent. There is considerable variability in these data, but a general trend toward lighter isotopic compositions occurs in recent times, which is consistent with a general warming trend that has occurred over this time period as seen in the air temperature record. The oxygen isotopic composition for calcite in the Benthos gravity core ranges from –4.82 percent to –6.12 percent. These isotopic values fluctuate from year to year and the record is filled with many periods of enrichment. The most notable peak is centered around 1903-1905 where there is a large positive excursion in the record. It is at this time where the most positive $\delta^{18}O$ values in the sediments are recorded, which also coincides with a decrease in the amount of calcium carbonate. Several other, smaller excursions are present appearing in 1928, 1937, 1948, 1957 and 1960. Aside from the positive excursions in the record there is a general baseline around which the record fluctuates prior to the mid-1980s where there is a shift toward lighter isotopic values. This more recent trend, which is also seen in the box core, is consistent with an increase in air temperature from the late 1980s to the early 1990s as seen in the historical record.

These preliminary data have led us to conclude that we required a 'newer' core that would include records from the very warm 1990s. We have recently collected a core from the same site as the 1983 core and are currently processing it.

Publications

Two draft manuscripts are in hand and will be completed in 2004.

Presentations

A presentation will be made by Phil Meyers at the December 2003 AGU Annual Meeting in San Francisco, California.

Significant Interactions

Preliminary interactions have started with Professors Peggy Ostrom and Nathaniel Ostrom at Michigan State University to explore possible collaborations.

Student Participation

Christina Knowlton, a Ph.D. student in the Department of Geological Sciences at the University of Michigan, has started work on this project.

CA4/I-08SE: Improving Interpretation of Bioaccumulation Data through Development of Tissue-Residue Toxicity Relationships

Principal Investigators: Lance J. Schuler, Southern Illinois University; Peter F. Landrum, Great Lakes Environmental Research Laboratory; and, Michael J. Lydy, Southern Illinois University

Approximately 60 percent of industrial chemicals that are present in the environment cause baseline or narcotic toxicity (Veith et al, 1983). Narcotic chemicals for the purposes of this study, are defined as anesthetics which are hypothesized to have nonspecific and reversible binding in nature and are assumed to elicit their tocix effects by disrupting the lipid bilayer resulting in loss of selective permeability and ultimately death. Chemicals that have been classified as narcotics include chlorinated benzenes, PAHs, and PCBs (see Russom et al, 1997 for a review). In addition to death, exposure to narcotic chemicals also may affect a variety of sublethal processes including growth, reproductive capacity and developmental time (Kukkonen and Landrum, 1994; Fisher et al, 1999; Hwang et al, 2001).

In assessing the contaminant risk of narcotic chemicals to aquatic biota, external contaminant concentrations in various environmental media (e.g., water, sediment, soil) have traditionally been used as a surrogate for the internal target site concentration that is required to produce an effect. As such, external concentrations of narcotics required to produce acute or chronic toxicity have been shown to vary by orders of magnitude (Van Wezel and Opperhuizen, 1995). This variability occurs because estimates based on environmental concentrations describe the intrinsic toxicity as well as bioaccumulation potential of the contaminant, which is influenced by various biotic and abiotic factors (McCarty and Mackay, 1993). Thus, it is desirable to establish a method to reduce the variability and uncertainty associated with measuring and reporting toxicity.

McCarty and Mackay (1993) proposed the use of internal body residues for examining the relationship between bioaccumulation and subsequent effects on biota. The advantages of this approach over the traditional environmental media-based dose are the implicit consideration of both contaminant bioavailability and multiple exposure routes. Based on empirical and theoretical studies, McCarty et al (1992) developed the critical body residue (CBR) approach, which has been defined as the internal residue concentration that produces 50 percent mortality. According to the 'narcosis hypothesis' for poorly metabolized nonpolar organic compounds, a constant toxic threshold exists independent of exposure concentration, exposure conditions and time (Van Hoogen and Opperhuizen, 1988). Toxicity based on internal residue concentrations has been shown to be relatively constant within the toxicokinetic-limited time frame for acute lethal narcosis in fish ranging from 2 to 8 $mmol \cdot kg^{-1}$, while chronic mortality hs been determined to be an order of magnitude less (Sijm et al, 1993; Van Wezel and Opperhuizen, 1995; McCarty et al, 1992).

Many studies have examined lethal body residues for a variety of narcotic chemicals over relatively short exposure times; however, the temporal dependency of lethal body residues needs to be further studied in order to improve/evaluate the utility of the body residue as a dose metric for assessing adverse effects to aquatic biota. Therefore, the objectives of this study were to establish lethal body residues of

two narcotic chemicals at differing exposure intervals up to 28-d for three species of freshwater amphipods; and to evaluate the toxicity of biotransformation byproducts.

Materials and Methods

Organisms. Three invertebrate species were selected for use in the study that included the amphipods *Hyalella azteca* (juvenile) and *Diporeia* spp. (juvenile), and the midge *Chironomus tentans* (3rd instar). *H. azteca* and *C. tentans* were chosen because they have been recommended by the US EPA for sediment toxicity testing (U.S. EPA, 1994; U.S. EPA, 2001) and because of their ecological importance and geographical distribution. The amphipod *Dioreia* spp. was used because the organism is an important component of the Great Lakes food webs and its biology differs greatly from that of *H. azteca* and *C. tentans*.

Experimental Design. Toxicity tests were conducted using [^{14}C]-radiolabeled fluoranthene. All experiments employed an aqueous exposure route. The spiking procedure consisted of adding the predetermined amounts of fluoranthene (radiolabeled and non-radiolabeled) using acetone as the carrier solvent to a bulk aliquot of water. The volume of carrier was less than 100 μl per L of test water in all exposures. The time-dependent acute toxicity for each species was examined using 10-d (*C. tentans*) and 28-d exposures (*H. azteca* and *Diporeia*). Experiments involving *H. azteca* and *C. tentans* were conducted in Precision Scientific Environmental Chambers (Chicago, Illinois) maintained at 23ºC with a 16 light: 8 dark photoperiod. *Diporeia* was exposed at 8ºC with no light to approximate their natural habitat. All organisms were exposed to a series of five contaminant concentrations, predetermined from range-finding experiments.

Exposure water concentrations were monitored before and after each daily water change by removing a 2 ml water sample and counting via LSC. *H. azteca* and *C. tentans* were fed YCT daily (note that route of exposure is not important, since all measurements will be linked to body residue levels). Mortality was assessed daily and remaining organisms at the end of the 28-d exposures, alive and dead, were removed and body residues measured using LSC.

The accumulation kinetics for *H. azteca* were determined at exposure times of 0.25, 0.5, 1, 2, 4, 7, and 10-d. Whereas, the accumulation was determined for *Diporeia* spp. at 1, 2, 4, 8, and 16-d. At each sampling time, three replicates were removed randomly from each concentration. Live organisms were removed from the water, for two of the replicates, rinsed, blotted dry and weighed to the nearest 0.01 mg using a Mettler analytical balance (Toledo, Ohio). The organisms were then analyzed using LSC.

Lipid content of live animals was measured at the beginning and end of each experiment, and if organisms were available at 10-d, using the colorimetric method described in Van Handel (1985).

Mortality data was analyzed using Probit Analysis with SAS® to estimate LC_{50} values based on environmental concentrations and lethal body residue values (LR_{50t}) corresponding to 50 percent mortality based on residues determined from dead organisms. The time dependency of the lethal residue data was examined by fitting the data to the following damage assessment model (DAM) proposed by Lee et al (2002).

$$LR_{50}(t) = \frac{D_L / k_a}{\frac{1}{\left(1 - e^{-k_e \cdot t}\right)} \times \left(\frac{e^{-k_r \cdot t} - e^{-k_e \cdot t}}{k_r - k_e} + \frac{1 - e^{-k_r \cdot t}}{k_r} \right)} \quad (1)$$

where:

$LR_{50}(t)$ is the time-dependent lethal residue ($\mu mol \cdot g^{-1}$),
D_L / k_a is the toxic damage level required to cause 50 percent mortality ($\mu mol \cdot g^{-1} \cdot h^{-1}$),
k_e is the compound elimination rate coefficient (h^{-1}),
k_r is the first-order rate constant for recovery (h^{-1}), and
t is time (h).

Results

Mortality. In *H. azteca* experiments, mortality was monitored for 28 d and the controls in each experiment exhibited less than or equal to six percent mortality. *H. azteca* exhibited a strong dose response relationship to increasing fluoranthene concentrations in the water. Fluoranthene LC_{50} concentrations in *H. azteca* ranged from a 5-d LC_{50} of 188.6 µg/L (174.6–203.7, 95 percent Cl) to a 28-d LC_{50} of 59.0 µg/L (51.0–68.2, 95 percent Cl). After approximately 18 d of exposure to fluoranthene, *H. azteca* reached an incipient LC_{50} concentration of 66.1 and 60.1 µg/L for two different experimental trials.

In the *C. tentans* exposures, mortality was monitored for 10 d. Control mortality was three percent and ten percent at 10 d in our two experiments. The LC_{50} decreased rapidly from 2 to 6 d, after which the LC_{50} remained stable at approximately 40 µg/L. The LC_{50} concentrations ranged from 175.5 µg/L at 2 d, 74.3-85.3 µg/L at 4 d, and 34.5-37.2 µg/L at 10 d.

Control mortality in *Diporeia* experiments ranged from seven percent in 10-d exposures to ten percent in 28-d exposures. There was not sufficient mortality at 10 d to obtain an LC_{50} estimate, however; the 28-d LC_{50} concentration was 95.5 µg/L (68.9-126.8, 95 percent Cl). Incipient lethal levels were not achieved following 28 d of exposure.

Lethal Residues. The LR_{50} concentrations were calculated from the mean lethal residue of individual dead organisms in each exposure concentration. Replicate beakers were nondestructively sampled at each time point, thus allowing LR_{50} concentrations to be determined at multiple times during the 28-d exposures for each toxicant. Sufficient mortality did not occur until 2, 5 and 10 d to obtain LR_{50} estimates for *C. tentans*, *H. azteca* and *Diporeia*, respectively. The LR_{50} concentrations declined significantly with time for each species. LR_{50} values for *C. tentans* ranged from 0.43 $\mu mol/g_{ww}$ at 2 d to 0.17 $\mu mol/g_{ww}$ 10 d. LR_{50} values for *H. azteca* ranged from 3.19 $\mu mol/g_{ww}$ at 5 d to 0.80 $\mu mol/g_{ww}$ at 28 d. LR_{50} values for *Diporeia* ranged from 9.97 $\mu mol/g_{ww}$ at 10 d to 3.67 $\mu mol/g_{ww}$ at 28 d.

The LR_{50} concentrations of fluoranthene show a strong time dependency for *C. tentans*, *H. azteca*, and *Diporeia* with values dropping two- to four-fold over the time course of the exposures. *C. tentans* was very sensitive to fluoranthene, exhibiting initial LR_{50} residues below 0.5 $\mu mol/g_{ww}$ after which the residues declined

to an asymptote or incipient LR_{50} value of 0.20 $\mu mol/g_{ww}$. *H. azteca* LR_{50} values dropped rapidly for the 10 d exposure and then approached an incipient LR_{50} value of approximately 1.0 $\mu mol/g_{ww}$. *Diporeia* LR_{50} values also dropped rapidly, however; no incipient value was obtained by the end of the 28-d exposure. These LR_{50} values together with a second measure of toxicity termed mean lethal residue (MLR), which is defined as the mean residue of the dead organisms for a given treatment level at exposure time corresponding to the lethal time at 50 percent mortality (LT_{50}), are modeled using the DAM to examine the time-dependent toxicity.

Biotransformation. *H. azteca* and *C. tentans* each possess a greater ability to biotransform fluoranthene than does *Diporeia*. The concentration of fluoranthene in the water seemed to have relatively little effect on the rate at which metabolites were formed in *H. azteca* and *C. tentans*. After 4 h of exposure, 45.5 to 61.5 percent of the total C^{14} activity in *H. azteca* was determined to be parent compound with a mean of approximately 56 percent (±2.6, SE) among all exposures. Of the remaining activity, three percent (±0.5, SE) was present as nonaqueous metabolites, 39 percent (±2.7, SE) as aqueous metabolite, and one percent (±0.3, SE) as bound material. In the *C. tentans* exposures, the amount of parent compound in the organism ranged from 72.3 to 85.1 percent with a mean of 78.9 percent (±2.1, SE) after 24 h. Of the remaining radioactivity, approximately 11 percent (±1.3, SE), eight percent (±1.0, SE), and 2.5 percent (±0.2, SE) was associated with polar metabolites, aqueous metabolites, and bound material, respectively. *Diporeia* has a limited ability to biotransform organic chemicals. Following 10-d exposure to fluoranthene, less than 95 percent of the C^{14} activity (corrected for initial purity) was found as parent compound.

Project Summary

The first goal of the project was to evaluate the time-dependent toxicity of fluoranthene for the three invertebrate test species. The outcome of this portion of the study was significant in that we showed that the toxic response to fluoranthene was not constant over the time course of the experiment. This contradicts the "critical body residue theory" which states that the lethal body residue will be constant regardless of exposure concentration or exposure time. Therefore we conclude that the observed temporal variability in lethal body residues is not governed exclusively by toxicokinetic processes alone, but rather in conjunction with toxicodynamic processes. This is an important consideration when examining data as part of a hazard assessment where long-term body residue data is necessary and needed.

As part of evaluating the temporal variability in lethal residues, the influence of lipid normalization among species was examined. There were significantly different lipid levels among the three test species with *C. tentans*, *H. azteca*, and *Diporeia* comprising approximately 1.2, 2.0, and 6.0 percent lipid, respectively. This variance partially explains the differences in $LR_{50(ww)}$ where *C. tentans* having the lowest lipid levels was most sensitive and *Diporeia* with the highest lipid levels was the least sensitive. After normalizing to lipid content there were no differences between replicated experiments for either *C. tentans* or *H. azteca*. The overall variability among species on a body residue basis also was reduced by approximately 50 percent. However, when comparing lipid normalized LR_{50} levels

at similar exposure times among species, there are still significant differences that cannot be explained by lipid content alone.

$LR_{50(lipid)}$ values for narcosis to fluoranthene have been previously reported as approximately 100 μmol/g. The $LR_{50(lipid)}$ values for *H. azteca* and *Diporeia* range from 85 to 128 μmol/g, suggesting that narcosis is the toxic mode of action, whereas the $LR_{50(lipid)}$ value of 33 μmol/g for *C. tentans* is much lower, suggesting a mode of action other than narcosis.

The enhanced toxicity of fluoranthene to *C. tentans* as compared to the other species may be a result of the larger fraction of polar metabolites found in its tissues. The biotransformation of PAHs may result in the production of reactive toxic metabolites, which when compared to the parent compound, would be expected to require less chemical to achieve toxicity. Analysis of the midge extracts has revealed that most of the polar metabolite fraction is comprised of a single compound. This compound is currently being isolated so further analysis can be performed using GC-MS, which will allow for definitive identification.

Publications

Schuler, L.J., P.F. Landrum, M.J. Lydy. 2003. Toxicity of fluoranthene to *Hyalella azteca*, *Chironomus tentans* and *Diporeia* spp. *Environmental Science and Technology*. (submitted)

Wilcoxen, S.E., P.G. Meier and P.F. Landrum. 2003. The toxicity of fluoranthene to *Hyalella azteca* in sediment and water-only exposures under varying light spectra. *Ecotoxicology and Environmental Safety* 54: 105-117.

Presentations

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Time-dependent toxicity of fluoranthene to *Hyallella azteca*, *Chironomus tentans* and *Diporeia* spp. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Austin, Texas.

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Time-dependent toxicity of fluoranthene using *Hyalella azteca*. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Austin, Texas.

Schuler, L.J., P.F. Landrum and M.J. Lydy. 2003. Body residues: implications in ecotoxicology and hazard assessment. Great Lakes Seminar Series at NOAA Great Lakes Environmental Research Laboratory. October 24. Ann Arbor, Michigan.

Schuler, L.J. and M.J. Lydy. 2002. An assessment of the time-dependent toxicity of floranthene using *Hyalella azteca*. Society of Environmental Toxicology and Chemistry (SETAC) National Meeting. November. Salt Lake City, Utah.

Schuler, L.J. and M.J. Lydy. 2002. Preliminary assessment of the time-dependent toxicity of fluoranthene using Hyalella azteca. Society of Environmental Toxicology and Chemistry (SETAC) Regional Meeting. May. Vicksburg, Mississippi.

Significant Interactions

This project has generated significant amounts of collaboration between Great Lakes Environmental Research Laboratory and Southern Illinois University. In addition, Dr. Landrum has established an adjunct professorship within the Department of Zoology at Southern Illinois University and is currently a dissertation committee member for Lance Schuler.

Additional Funding

Society of Environmental Toxicology and Chemistry (SETAC) and Proctor & Gamble Company Global Fellowship for Doctoral Research in Environmental Science.

Student Interaction

Schuler, Lance. Ph.D. expected 2005. Disseration, "Collection and interpretation of body residue-effects data for use in hazard assessment." Department of Zoology and Fisheries and Illinois Aquaculture Center, Southern Illinois University.

CA4/I-09SE: Evaluating Seasonal Changes in Net Basin Supply for Lake Michigan-Huron Since 1950

Principal Investigators: Steven L. Forman, University of Illinois at Chicago; Brent Lofgren, Great Lakes Environmental Research Laboratory; and Erin Argyilan, University of Illinois at Chicago

Warming air temperatures, decreased duration of lake and river ice cover, and increasing winter runoff in the Great Lakes reflect regional climate and hydrologic changes that are consistent with patterns of Northern Hemispheric warming documented during the 20th century. This study evaluates trends in temperature, precipitation, and streamflow data for 27 subbasins in the Lake Michigan watershed from 1948 to 2000. The objective of this contribution is to identify specific mechanisms that contribute to increasing winter runoff and decreasing spring runoff to Lake Michigan-Huron during the 20th century. Increases in winter runoff to Lake Michigan observed from 1948 to 2000 are driven by changes in precipitation and temperature that occur in the months of January, February, and March. Analyses of precipitation data from 1948 to 2000 detect increasing moisture to the region in January. Days with precipitation in January rose by four to six days in Northwest, 3.5 to seven days in West, and 3.5 to 5.5 days in East subbasins, reflecting increases of approximately 15 to 20 percent. January snow days rose by approximately one to seven days with the largest changes occurring in Northwest subbasins. Total precipitation increases by 40 to 70 percent in North, Northwest, and West subbasins, and by 25 to 60 percent in the East over the 53-year record. Decreases in the extent of lake ice and overlake evaporation may prove to be a contributing mechanism to rising precipitation in these subbasins. The number of days with a mean minimum temperature above 0˚C has increased by 0.5 to three days. Thus, February air temperatures increasingly favor winter rain events and melting of existing

snowpacks. Widespread rising trends in streamflow are evident in February and reflect less than five percent to greater than 100 percent increases in discharge relative to mean values from 1948 to 2000. March data reflects fewer days with mean maximum and minimum air temperatures less than 0˚C since 1948. Minimum air temperature are greater than 0˚C for 1.5 to 4.5 more days whereas maximum air temperature is greater than 0˚C for three to six more days in March. The combination of increasing precipitation and fewer days of subzero temperatures have facilitated large-scale hydrologic response in the form of increasing winter discharge. Rising trends in February discharge are evident in 11 of 21 streamflow records analyzed. Increasing February streamflow occurs at rates between 0.7 and 2.9 mm/decade over the land surface. Temperature changes are most evident in North, Northwest, and East subbasins. These basins exhibit distinct periods of positive anomalies in precipitation days and snow days during the 1970s and 1990s but provide evidence of long-term shifts in climate from January to March favoring rainfall events and earlier melting of snowpacks.

The results of this contribution indicate complex spatial changes in climate and hydrologic response throughout the Lake Michigan basin from 1948 to 2000. An increase in January moisture reflects shifts in seasonal precipitation that are consistent with predictions for wetter winter conditions projected for the 21st century by climate change scenarios based on HadCM2 input. Positive anomalies in January snow days and February streamflow are most apparent post 1965 and are coincident with a shift from dominance of a meridional to zonal atmospheric flow pattern over the Great Lakes region. Continuing work will focus on identifying atmospheric mechanisms that drive the observed shifts in precipitation and air temperature in the Lake Michigan basin during the months of January, February, and March. Specifically we will focus on changes in ice cover that may contribute to increased convection or evaporation and rising January precipitation.

Publications

Argyilan, E.P., S.L. Forman, and B.M. Lofgren. 2003. Twentieth century increases in winter runoff to Lake Michigan-Huron: potential links to climate change. *Proceedings of the International Association of Great Lakes Research Annual Meeting*. Chicago, Illinois. June 22-26.

Presentations

Argyilan, E.P., S.L. Forman, and B.M. Lofgren. 2003. Twentieth century increases in winter runoff to lake Michigan-Huron: potential links to climate change. International Association of Great Lakes Research, Annual Meeting. Chicago, Illinois. June 22-26.

Argyilan, E.P., S.L. Forman, and B.M. Lofgren. 2003. Twentieth century changes in the winter hydrology of the Lake Michigan basin: potential links to climate change. State of the Lake – Lake Michigan Annual Meeting. Muskegon, Michigan. October 21-22.

Argyilan, E.P., S.L. Forman, B.M. Lofgren, and T.E. Croley II. 2003. Evaluating changes in winter climatology and hydrology of the Lake Michigan basin

from 1948 to 2000. Great Lakes Environmental Research Laboratory. Ann Arbor, Michigan. September 11 – invited speaker.

Significant Interactions

This project has resulted in email inquiries from staff at the Illinois State Water Survey and the Great Lakes Environmental Research Laboratory. Researchers at the Illinois State Water Survey have found that our results are consistent with increasing winter air temperatures for Illinois. In addition, researchers at the Great Lakes Environmental Research Laboratory have expressed an ongoing interest in the spatial variability of climate change determined in this research. Future work will involve incorporating ice cover data collected by Dr. Raymond Assel of the Great Lakes Environmental Research Laboratory. In addition, other lab researchers have requested that we expand the study to other Great Lakes basins.

Student Participation

Argyilan, Erin P. Department of Earth and Environmental Sciences, University of Illinois at Chicago. PhD candidate with projected date of completion August 2004.

CA4/I-10SE: In-Situ Simultaneous Bottom Boundary Layer Measurements of Flow and Sediments in the Great Lakes

Principal Investigators: Chin H. Wu, University of Wisconsin-Madison and David J. Schwab, Great Lakes Environmental Research Laboratory

Background

Knowledge of boundary layer processes in the coastal area is crucial to the understanding of nearshore-offshore transport in the Great Lakes. In recent years, considerable progress has been made in developing a model for Lake Michigan that integrates hydrodynamic, wind-wave, and sediment transport sub-models to simulate sediment resuspension and transport under the impact of episodic events (Beletsky et al, 2000; Lou et al, 2000; Schwab et al, 2000). Previous results from this integrated numerical model show many of the lake-wide turbidity patterns as observed in satellite imagery but fall short to describe the detailed sediment plume features, particularly the spiral eddy in the southeastern part of the lake and rapid decrease in turbidity with depth (Lou et al, 2000; Schwab et al, 2000). Possible reasons for the missing features in the model can be attributed to the following:

- Inaccurate estimate of bottom shear stress induced by wave-current interactions.
- Only a uniform sediment size without the information of a spectrum of particle sizes, settling velocities, and cohesive flocculation.
- A depth-averaged sediment concentration but not a vertical turbidity profile.

Therefore, continuing efforts on improving the integrated numerical model by accurate representations of both bottom shear stresses induced by wave-current interaction and sediment erodibility (critical shear stress and erosion rate) are in progress (Schwab, 2002). In addition, simultaneous measurements of the turbidity (resuspension, deposition, and sediment transport) and associated near-bed flow

and turbulent structures induced bottom stresses are needed to further improve our understanding of nearshore-offshore transport in the Great Lakes.

To date significant efforts have been devoted to develop *in situ* instrument packages for measuring both flow and suspended sediment in the bottom boundary layers. These instrument packages usually include electromagnetic current meters (EMCM), acoustic Doppler current profilers (ADCP), acoustic Doppler velocimeters (ADV) for measuring velocity field, optical backscatter sensors (OBS) or acoustic backscatter sensors (ABS) for measuring sediment concentration, and cameras or sector scanning sonar for estimating bottom roughness. While these *in situ* instrument packages can provide valuable information for both flow and suspended sediment in the bottom boundary layers, local inconsistencies, as well as, limitations in the temporal and spatial scales for instrument measurement, impose challenges for estimating sediment resuspension. Therefore, the need to address potential impacts of different temporal and spatial measurement scales is crucial to further improve our basic understanding of the bottom boundary layer in nearshore and offshore areas. In addition, we need to further address the fundamental issues of separating current-wave-turbulence signals to accurately estimate bottom shear stress, and quantifying or directly measuring sediment resuspension within the combined wave-current environment.

The objectives of the proposed research is to deploy our current instrument package, *Acoustic Doppler Velocity, Current Profiler, and Sediment Optical Imaging, and Time Domain Reflectometer System* (ADV-CP-SOI-TDR) with the planning summer work by the Great Lakes Environmental Research Laboratory to simultaneously measure high spatial and temporal resolutions of flow and near-bed turbulence structure, and sediment concentration profiles under the wave-current environment; to estimate bottom shear stresses under a wave-current environment by applying or developing current-wave-turbulence separation techniques; and, to measure resuspension rate and critical shear stress of bottom sediment under the current-wave environment.

We will collaborate with GLERL scientists to simultaneously measure flows and sediment profiles, and the data will be used for calibrating models and testing the new wave-measuring ADCP (Schwab 2002). The proposed project addresses the fundamental issues of separating current-wave-turbulence signals to accurately estimate bottom shear stress, and directly measuring sediment resuspension within the wave-current environment. Moreover, this unique feature of the *in situ* ADV-CP-SOI-TDR can be used to estimate cohesive sediment erosion rates directly in natural combined wave-current condition. We have successfully tested the first phase of the ADV-CP-SOI-TDR instrument system in Madison Lake, Wisconsin. Currently we are developing an underwater micro-computer digital imaging system for quantifying particle sizes, deposition, and bedform features. With additional support from the University of Wisconsin Sea Grant, we believe that the scientific goals for the development and deployment of the *in situ* technology in the proposed project will lead to external funding to work on challenging sediment transport issues on the Great Lakes.

Project Synthesis

The ADV-CP-SOI-TDR instrument system was deployed at 10 m and 20 m water depths off of St. Joseph, Michigan in the fall of 2002. Unfortunately, the instrument package leaked and all data was lost for this deployment. The instrument package was repaired and redeployed at the same site in September 2003. The instrument was retrieved in November 2003 and appears to have successfully collected data. Data analyses and synthesis will be occurring during the coming months in order to advance the objectives of this project.

CA4/I-11: Great Lakes Summer Student Fellowship Program

Principal Investigators: Thomas H. Johengen, University of Michigan and Stephen B. Brandt, Great Lakes Environmental Research Laboratory

The Cooperative Institute for Limnology and Ecosystems Research and the Great Lakes Environmental Research Laboratory implemented the Great Lakes Summer Student Fellowship Program in 1998. To date, there have been 76 fellows supported by this program.

For summer 2003, 13 student fellow positions were selected from 59 applications, with preference given to currently enrolled undergraduate students or those who have recently graduated. Graduate applications were also considered. Of those selected, eight were undergraduates, one was recently graduated, and four were graduate students (two master's and two doctoral); nine were female and four were male. Each student fellow worked under the mentorship of an individual scientist or professional in a broad range of fields.

Student Fellow	**Academic Institution**	**Fellowship Field**
Raman Agrawal	Michigan State University	Data Analysis
Alexandra Belinky	University of Michigan	Aquatic Biology
Jarrod Dalton	University of Michigan	Data Analysis
S. Elizabeth Graham	University of Michigan	Computer Graphics Programmer
Carrol Hand	Barnard College	Database Development
Kirsti Huhta	Saint Joseph College	Ecosystem Ecology
Leonard Kofman	University of Michigan	Ecological Modeling
Sarah Kolascz	Kalamazoo College	Maritime History
Tu-Van Le	University of Florida	Biochemistry
Jyoteshwar Nagol	University of Toledo	Remote Sensing Technology
Anna Ritchie	Hawaii Pacific University	Aquatic Biology
Kirsten Rosenkrands	Kalamazoo College	Aquatic Ecology
Jennifer Weller	Western Michigan University	Geographic Information System

All student fellows were University of Michigan guest students working with either a GLERL or CILER mentor mostly in Ann Arbor, Michigan except for one fellow who worked in Alpena, Michigan, one fellow who worked in Kalamazoo, Michigan, and one fellow who worked in Gainesville, Florida.

CA4/I-12: Great Lakes Seminar Series

Principal Investigators: David F. Reid, Great Lakes Environmental Research Laboratory; Rochelle Sturtevant, Michigan Sea Grant College Program and Thomas H. Johengen, University of Michigan

One of the most productive means to enhance research collaborations between NOAA and the academic research community is to facilitate and encourage communication and networking. One approach to doing this is the implementation of a seminar series of invited speakers and targeted topical areas of focus. CILER has co-sponsored the Great Lakes Seminar Series since July 2001. Speakers are solicited in a broad range of disciplines encompassing all of our research theme areas. In FY 2003, 18 speakers presented seminars.

Seminar Presentations

Lake level monitoring using space geodetic technologies. July 9, 2002. C.K. Shum, Laboratory for Space Geodesy and Remote Sensing Research, Ohio State University; and Jeff Reutter, Ohio Sea Grant Program and F.T. Stone Laboratory.

Fish species discrimination using broadband acoustics. July 30, 2002. Gerald F. Denny, Scientific Fisheries Systems, Inc.

Ecosystem dynamics: satellite technology and trophic change. August 13, 2002. Judith Wells Budd, Michigan Technological University.

Effects of omnivory in marine planktonic food webs. September 24, 2002. Robert Ptacnik, Institute for Marine Research, Kiel, Germany.

Boundary mixing over sloping and rough topography: pathways of energy transfer. October 1, 2002. Sally MacIntyre, Marine Science Institute, University of California-Santa Barbara.

Reducing vulnerability to climate variability through integrated assessments: CLIMAS and seasonal forecasts. November 14, 2002. Holly C. Hartmann, Department of Hydrology and Water, University of Arizona.

Western Lake Erie monitoring and eco-informatics at the Lake Erie Center. November 21, 2002. Tom Bridgeman and Neela Akhouri, Lake Erie Center, University of Toledo.

Sediment transport modeling with application to Lake Michigan. December 4, 2002. Mary Cardenas, Harvey Mudd College.

Ballast water deoxygenation can prevent aquatic introductions while reducing ship corrosion. January 16, 2003. Mario N. Tamburri, Alliance for Coastal Technologies, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science.

Functional and structural shifts in the near-shore algal community of the Great Lakes: the response to exotic mussels. March 25, 2003. Rex Lowe, Bowling Green State University.

A changing Lake Erie fish community: unraveling the mechanisms involved. May 8, 2003. Stuart Ludsin, Great Lakes Environmental Research Laboratory.

The importance of the microbial food web in C- and P- transport through the base of the Great Lakes food webs. May 13, 2003. Robert T. Heath, Kent State University.

Modeling transport in lakes. May 20, 2003. Bernard Laval, University of British Columbia.

Beach profiles along Lake Erie. May 29, 2003. Tom Lippman, Ohio State University.

Characterization of hydrodynamics using HGM and ecoregions in Southeastern Michigan. June 2, 2003. David H. Merkey, University of Michigan.

Predicting the occurrence and impact of species invasions in the Great Lakes. June 2, 2003. Anthony Ricciardi, McGill University, Montreal, Quebec.

Observed climate variability and change: data issues and results. June 19, 2003. David R. Easterling, NOAA National Climate Data Center.

Report of and invasion: *Limnoperna fortunei* (Dunger 1857) or golden mussel in South America. June 30, 2003. Gustavo Darrigran, Facultad de Ciencias Naturales y Museo, La Plata, Argentina.

CA4/I-13: A Collaborative Faculty Position with Michigan State University to Enhance Research and Outreach Activities Between NOAA and Universities throughout the Great Lakes Basin.

Principal Investigators: Thomas H. Johengen, University of Michigan; William Taylor, Michigan State University; and Stephen B. Brandt, Great Lakes Environmental Research Laboratory

To extend the commitment and responsibilities of CILER to complement and coordinate the research activities between the Great Lakes Environmental Research Laboratory and universities throughout the Great Lakes basin, the creation of a collaborative faculty position was funded. This position focused on the development and coordination of research, teaching, and outreach programs between NOAA and Michigan State University that emphasize the development, testing, and use of Great Lakes aquatic system models, with additional research in marine coastal and estuarine systems. This research program facilitated the use of computer and laboratory facilities by collaborating with GLERL investigators and maintaining an active presence in the Department of Fisheries and Wildlife at Michigan State University. Extensive collaboration served to build complementary research programs that included community, population, and ecosystem ecology; limnology and oceanography; modeling of dynamic ecological systems; and aquatic ecology. The teaching program included classroom instruction and the mentoring and advising of graduate students. The outreach component included serving on scientific review committees as well as providing extension and outreach to international, national, and state agencies involved in research and management of the Great Lakes and coastal ecosystems.

This collaborative faculty position is currently filled by Dr. Scott Peacor, an ecosystem modeler. Dr. Peacor's research interests involve the study of aquatic ecosystems, and the development of mathematical frameworks to understand species interactions and their consequences to food web structure and dynamics. He examines how animal species representing diverse taxa in disparate systems are confronted with and respond similarly to common ecosystem processes. By representing such processes with conceptual and mathematical frameworks, they are made explicit, are clarified, and comparison between systems that can yield additional

insight is facilitated. He also utilizes controlled experiments to validate model predictions, to help illustrate their connection with natural systems, and to expose unforeseen processes when experimental results do not match model predictions.

Publications

Pfister, C.A. and S.D. Peacor. 2003. Variable performance of individuals: the role of population density and endogenously formed landscape heterogeneity. *Journal of Animal Ecology* 72: 725-735.

Werner, E.E. and S.D. Peacor. 2003. A review of trait-mediated indirect interactions in ecological communities. *Ecology* 84(5): 1083-1100.

Peacor, S.D. 2003. 2003. Phenotypic modifications to conspecific density arising from predation risk assessment. *Oikos* 100(2): 409-415.

CA4/I-14: Great Lakes Issues Identification Workshop

Principal Investigators: Brian J. Eadie, Great Lakes Environmental Research Laboratory and Thomas H. Johengen, University of Michigan

Introduction

On January 20–21, 2003 the NOAA Center for Sponsored Coastal Ocean Research (CSCOR), NOAA Great Lakes Environmental Research Laboratory (GLERL), and the Cooperative Institute for Limnology and Ecosystem Research (CILER) co-hosted a Great Lakes Issues Identification Workshop at the University of Michigan in Ann Arbor. The **focus of this workshop** was to identify major issues within the Great Lakes that fit within the overall goals of NOAA-CSCOR. This brief report summarizes the **results of this workshop** and will form the basis of any RFP that may subsequently be developed by CSCOR for a future Great Lakes Program. For purposes of program scale, past CSCOR programs have totaled approximately $1 million in funding over a five-year time period.

The CSCOR Coastal Ocean Program (COP) is a federal-academic partnership providing predictive capabilities for managing coastal ecosystems. The typical goals of a COP regional ecosystem study are to:

- Support NOAA's ecosystem and resource responsibilities.
- Foster collaboration between NOAA, universities, and states.
- Provide a path leading to operational or management products.

Projects funded through this program are typically those that span several disciplines with many investigators and are large scale and model based.

From 1998 through 2002 CSCOR, along with NSF-CoOP, GLERL, EPA Great Lakes National Program Office (GLNPO), and National Water Research Institute in Canada (NWRI) sponsored the Episodic Events Great Lakes Experiment (EEGLE) program (http://www.glerl.noaa.gov/eegle) in Lake Michigan. The focus of this program was nearshore-offshore transport and transformation of biogeochemically important materials and their impact on a whole lake scale.

The Great Lakes Issue Identification Workshop goal was to identify and prioritize a list of Great Lakes research issues compatible with CSCOR's goals and mission and to provide scientific information to assist decision makers in meeting the challenges of managing our nation's coastal resources (see *http://www.cop.noaa.gov/*). CSCOR targets critical issues that exist in the nation's estuaries, coastal waters, and Great Lakes. CSCOR translates its findings into accessible information and the transfer of technology to coastal managers, planners, lawmakers, and the public. Its aim is to create near-term and continuous improvements in environmental decisions affecting the coastal ocean and its resources.

Workshop Synthesis

By any measure, the Laurentian Great Lakes are one of the earth's greatest treasures. They contain about 18 percent of the world's surface freshwater supply and over 80 percent of the U.S. supply. The Great Lakes provide drinking water to over 40 million U.S. and Canadian citizens and water quality is thus an exceptionally important concern for the region. The Great Lakes also provide a locus for industry, tourism and a commercial and recreational fishery – the recreational fishery alone is valued at $4 billion annually.

Pressures associated from these multiple demands had devastating consequences on the Great Lakes and were epitomized by a declaration in the early 1970s that "Lake Erie was dead." Currently, the lakes are recovering from these devastating human impacts and water quality conditions have improved tremendously. The 1972 Great Lakes Water Quality Agreement between the U.S. and Canada set target loads for phosphorus that are calculated to restore the biological integrity of the Great Lakes ecosystem. The Great Lakes led the nation in the 1970s in nutrient control management and contaminant cleanup as well as in international and ecosystem-based approaches to management and control strategies of invasive species. Phosphorus targets were largely achieved by the early 1980s and contaminant levels continue to decrease or level off.

However, based on data collected over the past few years, the participants at the workshop agreed that new and continuing water quality and ecosystem health issues persist within the lakes and remain a challenge to managers.

Over the past 15 years the rate of species invasion into the Great Lakes has accelerated with substantial impacts on food webs and cycling of nutrients. The benthic food web and associated processes are very different from the 1980s and earlier. The most obvious example of these changes resulted from the introduction of zebra mussels (*Dreissena polymorpha*) in the early 1990s. They fundamentally altered energy transfer and nutrient cycling in the lakes and have been identified as a primary cause of the appearance of hazardous algal blooms of *Microcystis*, increased depletion of oxygen, and increased water clarity with resultant blooms of benthic macrophytes, such as *Cladophora*. In addition to the stresses associated with the zebra mussel invasion, the coastal areas of the lakes are being impacted by continuous changes in land use. These issues are now common in several areas including Saginaw Bay, Green Bay and Lake Erie. Also, there has been a massive reduction in *Diporeia* (a benthic amphipod and critical fish food) in several of the lakes. The strategy developed to manage the lakes by titrating phosphorus loads to

set levels of chlorophyll did not anticipate or include alteration of key processes in this ecosystem.

Given these recent perturbations and changes in community structure, the nutrient management strategy for the Great Lakes needs to be reexamined from a total ecosystem perspective.

While scientists, resource managers, and the public struggle to improve and sustain the quality of the Great Lakes by balancing the needs of multiple users, similar problems occur in other coastal areas.

Can we successfully manage ecosystems on the scale of the Great Lakes?

The models used in the 1970s to set nutrient input levels were first generation, but proved successful in forecasting lake response into the 1990s. Some recent data may imply that lake phosphorus concentrations are diverging from predictions. We now have a better understanding of how ecosystems work and need to improve the models by adding better physics, refined chemical and biological processes, incorporate the upper food chain, and importantly add new ecological components which were not present in the 1970s. Improved hydrodynamic models are now able to provide reliable information on lake circulation, transport of nutrients, and system-wide thermal structure. The importance of episodic events, land-lake coupling, and fundamental changes in nutrient dynamics and food webs need to be incorporated into a next generation of lake management tools. Concurrently, the validity of state-of-the-art models needs to be evaluated to test the validity and robustness of their outputs. This can be done in hindcast and forecast modes. Extensive databases, derived from research and monitoring programs that often extend back into the 1970s, can be used to test hindcast simulations. Furthermore, reasonably good meteorological data from approximately the past 50 years is available to drive circulation and thermal simulations.

Recommendations

The **consensus of this workshop** is that a new concerted research effort is needed to examine the impacts of recent ecological changes in the Great Lakes on water quality.

Proposals should be solicited to develop environmental forecasting tools for assessing and predicting changes in water quality and its consequences to the food web of the Great Lakes. Questions/issues identified at the workshop that should have priority include:

- Whether recent ecosystem changes have compromised eutrophication controls.
- Connections between water quality and undesirable ecosystem events such as taste and odor problems, harmful algal blooms, hypoxia, and fish die-offs.
- Impact of landscape changes on material fluxes across the land-lake interface.
- The effect of the benthic community on nearshore-offshore cycling and transport of materials.
- The role of physical processes (episodic events, interannual variability, and climate change) on basin ecology.
- The role of benthic-pelagic coupling in controlling key ecosystem processes.
- An examination of ecological resiliency in non-steady state environments.

The Great Lakes ecosystem is the most clearly definable regional entity under NOAA's purview and mission responsibilities, contains a suite of environmental stresses common to all coastal systems, and has a long history of bi-national and interagency partnerships and collaborations. Thus, the Great Lakes have the greatest potential for success in testing any regional approaches and for the development of ecosystem forecasting tools.

Workshop Program

The workshop was opened by a presentation from John Wickham describing COP goals and the format of the regional programs that they support. This talk was followed by a series of five invited presentations on topical areas important to the lakes. The presentations were given by senior investigators familiar with those areas and were intended to represent examples of new approaches and programs of appropriate scope, and as a place to begin the workshop discussions. Complete copies of the presentations have been posted to the web sites *http://www.glerl.noaa.gov/eegle/products/COP_workshop_2003* and *http://www.ciler.org/news*.

- *Extending NOAA's Prediction and Assessment Mission to Coastal and Marine Ecosystems – Don Scavia, NOAA-COP.* This presentation focused on ecological forecasting and current efforts to incorporate this concept into ecosystem planning.
- *Land-Margin Interactions: Three Venues Subject to Major Changes – Val Klump, University of Wisconsin-Milwaukee*. This presentation focused on developing a coastal research theme similar to NSF-LMER (Land-Margin Ecosystem Research) with emphasis on examining the roles of rivers, upwellings, etc. on coastal ecology. Management products would include improved predictions of alewife for salmon stocking decisions. This type of program would be a follow-on to EEGLE, building on information acquired in that project.
- *Potential CSCOR Projects: Major Issues in Lake Erie Research – Gerald Matisoff, Case Western Reserve University*. This presentation described a potential Lake Erie program that would focus on food-web changes and impacts, and include research on other major NOAA-COP interests such as hazardous algal blooms and hypoxia. This program would build on a large Lake Erie database and current EPA programs focused on the cause of phosphorus increase and hypoxia. The fisheries management products would be different, but still notable. Lake Erie has large signal-to-noise in many areas of interest. Large gradients would provide a major challenge for optical work and satellite-based algorithm development; massive sediment resuspension would provide a test for EEGLE products.
- *Retrospective (1953-2002): Hydrodynamic Modeling for Lake Erie – Dmitry Beletsky, University of Michigan and David Schwab, NOAA Great Lakes Environmental Research Laboratory.* This presentation discussed developing a retrospective analysis of one (or more) of the Great Lakes covering the past 45 years using well-calibrated hydrodynamic models to hindcast thermal structures, circulation and waves. These models would provide a means of isolating other major processes during major transition events (phosphorus load reduction, infestation of zebra mussels, etc.) and provide a framework for conducting detailed examination of a major ecosystem restoration.

- *Remote and in situ Optical Methods for Characterization of Ecosystem Level Physical and Biogeochemical Processes in the Great Lakes – Oscar Schofeld, Rutgers University and Steve Lohrenz, University of Southern Mississippi.* This presentation focused on opportunities for optical studies to improve algorithms for Great Lakes remote sensing products – this could be a part of a larger theme as well. The talk also described potential developments in observing systems that would facilitate additional in situ measurements offering opportunities to examine, synoptically, teleconnections among the lakes.

After these presentations and some plenary discussions, the workshop participants split into three workgroups with a common charge – to discuss the items that were presented and to identify new themes for Great Lakes research that addressed important research issues compatible to the goals and format of a COP regional program.

Workgroups met several times in the issues format where each group had representatives on all disciplines, and discussions focused on specific topical areas. Then, participants re-formed into new groups along disciplinary lines to continue to hone potential hypotheses and objectives. The three workgroup summary reports are presented below.

List of Participants

Participant	Affiliation	Email Contact	Discipline
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CLIMATE AND LARGE-LAKE DYNAMICS

Research conducted by CILER under this task originally focused on climate change, but has been broadened to include research involved with the interaction of large lakes and the atmosphere and their attendant influence on physical processes. Because large lakes of the world have a decided impact on their surrounding microclimate, and likewise are heavily influenced by regional climate, understanding the relationships between these large lakes goes beyond the scope of climate change. Included in this task are activities such as the study of heat flux into and out of large lakes, wind forecasts, hydrodynamic forecasting and coupled hydrosphere-atmosphere models.

CA4/II-01: The Impact of Episodic Events on Nearshore-Offshore Transport in the Great Lakes: Hydrodynamic Modeling Program

Co-Principal Investigators: Dmitry Beletsky, University of Michigan and David J. Schwab, Great Lakes Environmental Research Laboratory

Years one through four of this project were funded through CILER's cooperative agreement NA67RJ0148. Year five is funded through this current cooperative agreement. This study is part of the joint NSF/OCE NOAA/COP Great Lakes Project, a five-year multidisciplinary program on the impact of episodic events on the coastal ecosystem in the Great Lakes (EEGLE, Episodic Events - Great Lakes Experiment). The purpose of this project is to create a numerical modeling effort (in close cooperation with the observational program, meteorological modeling, sediment transport modeling, and ecological modeling), to identify, quantify, and develop prediction tools for the primary physical processes responsible for nearshore-offshore transport of biogeochemically important materials in the Great Lakes, and in Lake Michigan in particular. The hydrodynamic modeling program is designed to test the following specific hypothesis: that the forced, two-gyre vorticity wave response of the lake to episodic wind events, occasionally modified by stratification, is a major mechanism for nearshore-offshore transport in the Great Lakes**.** The recurrent springtime appearance of an extensive turbidity plume in southern Lake Michigan (Eadie et al, 1996) provides a unique opportunity to examine the two-gyre vorticity wave hypothesis during a period when a large volume of suspended material can act as a natural tracer of nearshore-offshore circulation patterns. The program studied this phenomena in Lake Michigan during winter and spring transition periods (thermal bar), in order to be able to compare cross-margin transport generated by purely barotropic processes in the winter to transport later in the spring when baroclinic processes may be more important.

A 2km bathymetric grid of Lake Michigan was prepared for use by all physical and biological models in the EEGLE project. The grid is based on the new, high-resolution bathymetry released by the National Geophysical Data Center (NOAA/NDGC). Meteorological data were collected and analyzed for the 1998-2000 period (including March 1998 output from the mesoscale meteorological model MM5 for Lake Michigan). Circulation and wave models were linked to a sediment transport model. We performed wave, hydrodynamic and sediment transport model

simulations for the March-April 1998 and March-April 1999 sediment plume events in Lake Michigan on a 2 km grid. Products are available at http://www.glerl.noaa.gov/eegle. Hydrodynamic model results showed significant offshore flow during these episodes. We also performed model simulations for the whole 1998-2000 EEGLE field program period and began analysis of 1998-2000 current observations in Lake Michigan to evaluate hydrodynamic model performance. Model run with MM5 winds during a six-day period in March 1998 showed improvement in simulated currents over the model run with objectively analyzed winds. Therefore, we obtained 30-day long MM5 winds for the resuspension event in March 1999 to explore this topic further. We also began comparison of modeled surface currents with HF-radar derived currents during the 2000 resuspension event. Particle trajectory model was applied for April-May 1999 and results were compared with drifter observations in southern Lake Michigan.

Sediment transport model results showed that wind waves are primarily responsible for sediment resuspension while currents move sediments along shore and offshore and therefore play an important role in creating the net erosion/deposition pattern in the lake. The sediment transport model produced a sediment erosion /deposition pattern qualitatively close to existing observations with most sediment deposition along the east shore of Lake Michigan. We performed model simulations of sediment transport in idealized basins in order to determine the cause of asymmetry of sediment deposition patterns in Lake Michigan. Eight sediment resuspension episodes were identified in 1998-2000 based on sediment model resuspension calculation. The 3D particle trajectory model was run for a three-day period corresponding to the main events to visualize nearshore-offshore physical transport.

The circulation model was revised as part of our work on creating the Great Lakes Modeling System (a system of models to hindcast, nowcast and forecast physical and biological conditions of the Great Lakes). A 1-D physical model was developed and linked to a biological model. A 3-D model results were also used in the biological model. Steady flow boundary conditions were implemented for 18 inflow tributaries and two outflows on the 2km Lake Michigan grid. A copy of the circulation model was provided to Ohio State University to be used in the nowcast/forecast system for Lake Michigan.

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Significant Interactions

We collaborated with Dr. Paul Roebber, University of Wisconsin-Milwaukee on improving the wind fields in the Lake Michigan circulation model; Dr. Changshen Chen, University of Georgia on physical-biological modeling; and Dr. John Vesecky, University of Michigan on model-HF radar current comparison. A copy of the circulation model was provided to Ohio State University to be used in the nowcast/forecast system for Lake Michigan. Results of the 2000 model runs were provided to HydroQual, Inc., and Baird & Associates to support their complementary research efforts.

CA4/II-03: Monitoring and Meteorological Conditions on Lake Champlain

Principal Investigator: Gerald P. Livingston, University of Vermont

The need for real-time meteorological data from Lake Champlain to support lake research, enhance lake weather predictions, and aid in navigation was known for many years. The opportunity to establish such a meteorological monitoring station at Colchester Reef arose in 1996 with funding from NOAA, the Lake Champlain Research Consortium, Lake Champlain Basin Program, and availability of a suitable site at the Colchester Reef navigational light through the U.S. Coast Guard. The Vermont Monitoring Cooperative also became a partner in the project and is responsible for data distribution and archiving. This state-of-the-art automated monitoring station provides high quality near real-time meteorological data to the National Weather Service (NWS) in Burlington, to a variety of researchers and resource managers, and to the general public, including boaters and other recreational users of Lake Champlain. The NWS uses these data to prepare wind and wave safety forecasts for commercial and recreational boaters and other lake users, and to anticipate and predict localized "lake effect" precipitation patterns. These meteorological data are being summarized on a monthly and seasonal basis. This database will be used by the NWS to train forecasters and as historic wind data for research activities on Lake Champlain. The Colchester Reef data are routinely used by a variety of researchers and resource managers to characterize the physical limnology of Lake Champlain, in spectral correlation techniques with water velocity, in atmospheric and water transport models for mercury and other pollutants, and to determine the feasibility of daily research activities on Lake Champlain. The Vermont Fish and Wildlife Department is using these data in a dye transport study

to predict the extent and duration of lampricide plumes off the mouths of the LaPlatte and Winooski Rivers, which empty into Lake Champlain. These data are also in high demand by commercial and recreational users of Lake Champlain. Vermont and New York Emergency Management officials also recognize the value of these near real-time data in the event of an emergency. As with any meteorological station, it is imperative to keep the sensors calibrated and keep the station in top operating condition. This requires continued funding to provide the manpower, equipment/sensor updates, calibrations, and general site upkeep necessary to provide uninterrupted high quality data. The funds awarded to this research project were used to do just that over the duration of the grant.

Publications

The following Lake Champlain Research Consortium Monographs have used data from the Colchester Reef meteorological station.

Manley, T. 2003. Hydrodynamics of the South Lake, Lake Champlain. (in press).

Manley, P.L., T.O. Manley and M. Watzin. 2003. Hydrodynamics of a large pockmark in Lake Champlain. (in press).

Gao, N. 2003. A mass balance assessment for mercury in Lake Champlain. (in press).

Presentations

Rosovsky, J., C. Waite, M. Pendleton, and P. Girton. 2001. VMC Meteorological Monitoring. 2001 Annual Cooperators Meeting of the Vermont Monitoring Cooperative, Burlington, Vermont, March 18, 2002. Near real-time data from Colchester Reef are published on the internet, on an hourly basis, by the NWS (Burlington) at: *http://www.erh.noaa.gov/btv/html/curreef.html* and on the Burlington Eco Info Project (EMPACT) web site at: *http://www.uvm.edu/%7Eempact/weather.php3*.

Significant Interactions

Broad support for this project assuring the continuous stream of high quality meteorological data from Colchester Reef has come from NOAA, NWS, States of Vermont and New York, Middlebury College, the State University of New York at Plattsburgh, St. Lawrence University, St. Michael's College, and the University of Vermont, as well as, numerous businesses and the general public. One example of a significant collaboration is the Vermont Monitoring Cooperative's (VMC) relationship with the NWS. VMC, a collaboration among the U.S. Forest Service, Green Mountain National Forest, State of Vermont, University of Vermont, several other universities and colleges, and many individual cooperators, provides near real-time meteorological data from Colchester Reef to the NWS for predictive purposes and distribution to the general public. VMC also functions as the archive and data manager for the Colchester Reef data, making the archived data available online and by request. The Colchester Reef data are also used in collaborative projects between researchers at Middlebury College and the University of Vermont.

COASTAL AND NEARSHORE PROCESSES

CILER research in coastal and nearshore processes has focused on both the marine and limnetic nearshore environments. CILER projects have studied coastal processes in the Great Lakes, Gulf of Mexico, South Atlantic Bight, and the northeastern coast of the United States. A particular emphasis has been the investigation of exchanges of materials from tributaries into the nearshore zone. Those investigations have covered a wide variety of disciplines including physical, chemical, and biological oceanography and limnology, and in many cases have combined all three fields. This variety of research is viewed as a major strength for CILER since a comparison among different coastal environments provides unique opportunities for insight into ecosystem structure and function.

CA4/III-01: Impact of Episodic Transport and Resuspension on Coastal Phytoplankton Processes: A Case Study of the Lake Michigan Recurrent Coastal Plume

Principal Investigator: Gary L. Fahnenstiel, Great Lakes Environmental Research Laboratory

This project is an ongoing project that had funding through CILER cooperative agreement NA67RJ0148. This study is part of the joint NSF/OCE NOAA/COP Great Lakes Project, a five-year multidisciplinary program on the impact of episodic events on the coastal ecosystem in the Great Lakes (EEGLE, Episodic Events - Great Lakes Experiment). Fieldwork for this study was completed during 1998-2000. Data synthesis is still ongoing and several manuscripts are currently under development. A brief synthesis of the results follows.

A large gradient in water-column light attenuation (KPAR) and concentrations of suspended particulate matter (SPM) was noted in southern Lake Michigan during the field program. Scattering was the dominant factor contributing to variability in light attenuation in the study area, especially at low wavelengths. Variability in particulate absorption was the primary source of variation in total absorption. Neither KPAR values nor SPM concentrations corresponded with chlorophyll (Chl) a concentrations, indicating no differences in phytoplankton biomass between plume- and non-impacted waters. Moreover, phytoplankton growth rates were also not correlated with SPM or KPAR, nor were significant differences noted between plume and non-plume stations. Phytoplankton growth rates appear to be regulated by a complex interaction of light, nutrients, and sediment. Sub-optimal maximum photosynthetic quantum yields were also indicative of constraints on phytoplankton growth. Diatoms and cryptophytes dominated the phytoplankton assemblages, often comprising greater than 85 percent of the Chl biomass. The positive associations of SPM concentrations and KPAR values agree with the relative contribution of diatoms to Chl a and KPAR values.

Publications

Bergman, T., G. Fahnenstiel, S. Lohrenz, D. Millie and O. Schofield. 2003. The effects of a spring resuspension event on *in situ* optical parameters and phytoplankton light utilization. *J. Geophys. Res* (in review).

Lesht, B.M., J.R. Stroud, M. McCormick, G.L. Fahnenstiel, M. Stein, L. Welty, and G.A. Leshkevich. 2002. An event-driven phytoplankton bloom in southern Lake Michigan observed by satellite. *Geophysical Research Letters* 29(8):18.1-18.4.

Chen, C., R. Ji, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, M. Jiang, T.H. Johengen, H.A. Vanderploeg, B.J. Eadie, J.W. Budd, M.H. Bundy, W. Gardner, J. Cotner, and P. Lavrentyev. 2002. A model study of the coupled biological and physical dynamics in Lake Michigan. *Ecological Modeling* 152: 145-169.

Fahnenstiel, G.L., C. Beckman, S.E. Lohrenz, D.F. Millie, O.M.E. Schofield and M.J. McCormick. 2002. Standard Niskin and Van Dorn bottles inhibit phytoplankton photosynthesis in Lake Michigan. *Verh. Internat. Verein. Limnol*. 28: 376-380.

Millie, D.F., G.L. Fahnenstiel, H.J. Carrick, S.E. Lohrenz, and O.M.E. Schofield. 2002. Phytoplankton pigments in coastal Lake Michigan: distributions during the spring isothermal period and relation with episodic sediment resuspension. *Journal of Phycology* 38: 639-648.

Fahnenstiel, G.L., R.A. Stone, M.J. McCormick, C.L. Schelske and S.E. Lohrenz. 2000. Spring isothermal mixing in the Great Lakes: evidence of nutrient limitation and nutrient-light interactions in a sub-optimal light environment. Can. *J. Fish. Aquat. Res.* 57: 1901-1910.

Lohrenz, S.E., G.L. Fahnenstiel, G. Kirkpatrick, C.L. Carroll and K.A Kelly. 1999. Microphotometric assessment of spectral absorption and its potential application for characterization of harmful algal blooms. *Journal of Phycology* 35: 143&1446.

Kelley, KA. and S.E. Lohrenz. 1999. Microphotometric analysis of light absorption characteristics for species within a recurrent coastal plume of Lake Michigan, (abstract). *Journal of the Mississippi Academy of Sciences* 44:83.

Presentations

Kelly, K.A., S.E. Lohrenz and G.L Fahnenstiel. 1999. Microphotometric analysis of light absorption characteristics for species within a recurrent coastal plume of Lake Michigan. Mississippi Academy of Sciences Annual Meeting. February 24-26. Tupelo, Mississippi.

Millie, D., G. Fahnenstiel, O. Schofield and S. Lohrenz. 1999. Impact of a recurrent sediment plume on Lake Michigan phytoplankton. Poster: ASLO Meeting. February 1-5. Santa Fe, New Mexico.

Lohrenz, S.E., O.E. Schofield, G.L. Fahnenstiel and D.F. Millie. 1999. Optical gradients in a recurrent coastal turbidity plume in southeastern Lake Michigan. ASLO Meeting. February 1-5. Santa Fe, New Mexico.

Fahnenstiel, G.L. and S.E. Lohrenz. 1998. Light absorption characteristics of spring phytoplankton in southern Lake Michigan. Society for International Limnology, XXVII Congress. August 9-14. Dublin, Ireland.

Lohrenz, S., G. Fahnenstiel and G. Kirkpatrick. 1998. Microphotometric assessment of spectral absorption and its potential application for characterization of harmful algal species. Phycological Society of America Annual Meeting. August 3-8. Flagstaff, Arizona.

Millie, D., G. Fahnenstiel, O. Schofield and S. Lohrenz. 1998. Impact of a recurrent coastal plume on Lake Michigan phytoplankton: a preliminary assessment. Phycological Society of America Annual Meeting. August 3-8. Flagstaff, Arizona.

Significant Interactions

This project has involved significant interactions between scientists at the Cooperative Institute for Limnology and Ecosystems Research, the NOAA/Great Lakes Environmental Research Laboratory, Rutgers University, University of Southern Mississippi, and the U.S. Department of Agriculture.

Student Participation

Kim Kelly, M. S., "Microphotometric analysis of light absorption characteristics for species within a recurrent coastal plume of Lake Michigan." Center for Marine Science, University of Southern Mississippi, 2001.

CA4/III-03: RAFOS and Shelburne Bay Program

Principal Investigator: Thomas O. Manley, Middlebury College

Shelburne Bay still remains an enigma with respect to its internal dynamics. While it does occasionally exhibit internal seiche oscillations at a period associated with that of the Main Lake (~ four days), it also exhibits a rather consistent diurnal (24 hour) period. Observations of both surface and deep currents have shown that the diurnal internal seiche period cannot be internal to Shelburne Bay. In order to account for bimodal circulation patterns set up within Shelburne Bay, the node (assuming uninodal structure) must be located to the north of Shelburne Bay and most likely in Burlington Bay. Two hypotheses have been proposed for the origin of the diurnal internal seiche within Shelburne Bay. First, it is created as part of a larger combined Burlington and Shelburne Bays system with the standing wave primarily aligned in a north-south direction. The second one requires a cross-lake internal mode existing from Willsboro Point to Shelburne Bay.

A specialized mooring array was deployed in early June 2002 to specifically look for the presence of both internal and surface cross-lake modes and was recovered in late August 2002. Analyses of these data are ongoing and will support other collaborative efforts in Lake Champlain. For example, Ken Hunkins, using pressure sensors located inside as well as outside Shelburne Bay, found two dominant surface seiche periods; one at four days that corresponds with the Main

Lake baroclinic mode and a much smaller amplitude wave with a period of approximately 35 minutes. While observed in many lakes, a barotropic (surface) mode can be forced by an underlying baroclinic mode, however, both can be observed at the same location. In Shelburne Bay, often the internal Main Lake mode is missing while the surface mode is present. Also of note is the fact that the surface barotropic mode from the Main Lake is an order of magnitude larger than the 35-minute period surface standing wave believed to be associated with Shelburne Bay itself. Hodographs of ADCP data (Sardilli, 1999) show that there appears to be net advective motion into and out of the Shelburne Bay but is dependent on the winds as well as the chosen layer (i.e., epilimnion or hypolimnion). One major outcome to this program was the creation of a new bottom bathymetry map for Shelburne Bay. A student at Middlebury College was working on the analysis of several other aspects of data taken within Shelburne Bay for a senior thesis, but then later dropped the project due to an overload in classes and student teaching.

Publications

Manley, P.L., T.O. Manley, M.C. Watzin and J. Gutierrez. 2002. Lakebed pockmarks in Burlington Bay, Lake Champlain: I. Hydrodynamics and implication of origin. This paper utilized some of the Shelburne Bay data collected during the 1999 field season. Submitted to the Lake Champlain Research Consortium Monograph.

Sardilli, D. 1999. The internal dynamics of Shelburne Bay. Senior thesis of Middlebury College, Department of Geology, 62 pp.

Gutierrez, Joshua. 1999. The general pockmark in Burlington Bay, Lake Champlain. Undergraduate thesis of Middlebury College, Department of Geology. 63 pp.

Barsotti, M.G., R. Pratt, J. Faye, T.O. Manley and M. Samadpour. 1999. Surface water source characterization to overcome operational complacency and aid source delineation. Proceedings of the 1999 Water Quality Technology Conference. Tampa, Florida.

Presentations

All senior thesis students gave presentations at the Vermont Geological Society and the Lake Champlain Research Consortium Student Symposium, both being held in the early spring of their graduating year.

Manley, T.O., P. Tillier and J.C. Gascard. 2002. Acoustically-tracked neutrally-buoyant Lagrangian drifters in Lake Champlain – a feasability study. Ocean Sciences Meeting. February 11-15. Honolulu, Hawaii.

Barsotti, M.G., R. Pratt, J. Faye, T.O. Manley and M. Samadpour. 1999. Surface water source characterization to overcome operational complacency and aid source delineation. Proceedings of the 1999 Water Quality Technology Conference. Tampa, Florida.

Manley, T.O., J.C. Gascard and P. Tillier. 1998. Acoustically tracked Lagrangian drifters in Lake Champlain. June 9-14. Green Bay, Wisconsin.

Significant Interactions

We have had significant interactions with the Champlain Water District (CWD) which initially funded the pilot program that later developed into the research program that has evolved to date. The water quality personnel are extremely interested in the results that come from this work in that it will eventually lead to better methods to obtain the cleanest water from Shelburne Bay. A better understanding of the dynamics operating in the Bay will, in turn, lead to better efficiency in the treatment and handling of raw lake water. They are also now developing plans to install a second water intake pipe onto their existing system. The hydrodynamics of the Bay will play an important part in the positioning of the second intake pipe. Interactions with NOAA and Middlebury College are very strong and we are continually working on the further analysis of the data. There has also been some interest by the biological community as to the location of specific planktonic species (within Shelburne Bay) in relation to the thermocline as well as the vertical migration of some species. Vertical migration was first observed in the ADCP data using backscattering.

Additional Funding

New funding was just received to continue work on the RAFOS and Shelburne Bay experiments. This funding was through the Lake Champlain Research Consortium and NOAA.

Student Participation

Sardili, D. The internal dynamics of Shelburne Bay, a senior thesis of Middlebury College, Department of Geology. 62 pp.

Dana Chapin was to complete another large section of data analysis from the Shelburne Bay data set but had to drop the thesis program mid-year after she realized that her student teaching, sports, and classes were too much to cope with.

CA4/III-05: The Impact of a Recurrent Coastal Plume on Phosphorus Dynamics and Production in Lake Michigan

Co-Principal Investigators: Thomas H. Johengen, University of Michigan and James B. Cotner, University of Minnesota

This research project represents one of twelve separately funded components of the parent proposal entitled "The Impact of Episodic Events on the Nearshore-Offshore Transport of Biogeochemically Important Materials in the Great Lakes (EEGLE)." Our project is designed to examine the influence of major episodic events on phosphorus (P) availability and dynamics in the southern basin of Lake Michigan. Efforts will focus on a recurrent coastal plume that develops in the spring. Understanding the impact of episodic events on P availability has important implications for ecosystem structure and function because primary productivity in this system is P-limited.

The goal of this project is to determine the importance of the recurrent coastal plume to the transport, composition and biological availability of P. To achieve this goal, we will fulfill the following objectives: (1) determine the potential sources, distributions and fluxes of P in the recurrent coastal plume, and (2) determine the impact of P associated with the recurrent coastal plume on phytoplankton and bacterioplankton production in Lake Michigan. Specifically, we will examine the impact of these suspended particles on microbial (heterotrophic bacteria and phytoplankton) community productivity and nutrient limitation through a combination of bioassays (growth rate measurements, alkaline phosphatase activity), nutrient chemistry and stoichiometry, and P regeneration rates.

During the three field years of the study (1998-2000) we conducted over 30 research cruises in southern Lake Michigan to examine the spatial and temporal patterns of nutrient dynamics and heterotrophic production in response to resuspension events and riverine inputs. During the cruises we conducted surveys of nutrient concentrations, nutrient limitation, bacterial abundance, chlorophyll concentrations and total suspended material. At selected sites we performed experiments on bacterial production, nutrient uptake kinetics and equilibrium reactions. In addition to the cruises, a multi-investigator (cross-project) experiment was conducted using meso-cosms to examine the individual and synergistic effects of riverine inputs and sediment resuspension on nutrient dynamics, bacterial production, and phytoplankton production. The last two years of activity were dedicated to completing all of the laboratory and data analyses, and in preparation of various manuscripts and scientific presentations.

Research Findings

Over the past decade, satellite imagery revealed the presence of an extensive plume of resuspended particles in late winter-early spring along a 300-km reach throughout southern Lake Michigan. Synoptic surveys of these events revealed that the total mass of resuspended material was equivalent to the entire external annual load. High turbidity could persist for approximately one month and exhibited patterns in offshore transport that coincided with areas of maximum sediment distribution in the basin. Sediments appeared to be rich in organic and inorganic nutrients and 10-fold increases in phosphorus concentrations were observed in areas of high resuspension. The input of these biologically limiting nutrients significantly stimulated heterotrophic production and measured rates were four times higher in regions affected by the plume than for background lakewater. Maximum rates were even higher than those typically observed during the summer despite extremely low temperatures (2°C or less).

Detailed microcosm experiments were conducted to tease apart the separate influences of riverine inputs and resuspension inputs that co-occur within certain regions of the coastal zone. Riverine nutrient inputs were found to be more readily available to the plankton community and stimulated heterotrophic and autotrophic production by approximately 11-fold versus three-fold for resuspension alone. It was estimated that even though the volume of lake directly under the influence of resuspension and coastal runoff is only around ten percent of the open lake, the amount of planktonic production in this region is comparable.

Variations in the magnitude and frequency of these resuspension events and coastal runoff significantly influence plankton dynamics and biogeochemical cycling in the nearshore zone and likely influence the interannual production of the lake ecosystem.

Publications

Chen, C., R. Ji, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, M. Jiang, T.H. Johengen, H.A. Vanderploeg, B.J. Eadie, J.W. Budd, M.H. Bundy, W. Gardner, J. Cotner and P. Lavrentyev. 2002. A model study of the coupled biological and physical dynamics in Lake Michigan. *Ecological Modeling* 152: 145-168.

Biddanda, B.A. and J.B. Cotner. 2002. Love handles in aquatic ecosystems: role of dissolved organic carbon drawdown, resuspended sediments and terrigenous inputs in the carbon balance of a Great Lake (Michigan). *Ecosystems*. 5: 431-445.

Cotner, J.B. 2002. Heterotrophic bacterial growth and nutrient limitation in large, oligotrophic lakes and oceans. *Verh. Internat. Verein. Limnol.* (in press).

Ji, R., C. Chen, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, T.H. Johengen, H.A. Vanderploeg, B.J. Eadie, M. Bundy, W. Gardner and J.B. Cotner. 2002. A coupled biological and physical model of Lake Michigan: influences of suspended sediments. *Ecological Modeling* 152:169-190.

Eadie, B., D. Schwab, T. Johengen, P. Lavrentyev, G. Miller, R. Holland, G. Leshkevich, M. Lansing, N. Morehead, J. Robbins, N. Hawley, D. Edgington and P. Van Hoof. 2002. Characterizing a major episodic event: a recurrent winter-spring plume in southern Lake Michigan. *J. Great Lakes Res*. 28(3):324-337.

Cotner, J.B. and B.A. Biddanda. 2002. Small players, large role: microbial influence on auto-heterotrophic coupling and biogeochemical processes in aquatic ecosystems. *Ecosystems* 5(2):105-121.

Biddanda, B., M. Ogdahl and J.B. Cotner. 2001. Dominance of bacterial metabolism in oligotrophic relative to eutrophic waters. *Limnol. Oceanogr.* 46:730-739.

Cotner, J.B., M.L. Ogdahl and B.A. Biddanda. 2001. Double-strained DNA measurement in lakes with the fluorescent stain PicoGreen and application to bacterial bioassays. *Aquatic Microbial Ecology* 25:65-74.

Cotner, J.B., T.H. Johengen and B.A. Biddanda. 2000. Intense winter heterotrophic production stimulated by benthic resuspension. *Limnology and Oceanography* 45:1672-1676.

Eadie, B., D. Schwab, R. Assel, N. Hawley, M. Lansing, C. Miller, N. Morehead, J. Robbins, P. Van Hoof, T. Johengen and P. Lavrentyev. 1996. Development of recurrent coastal plume in Lake Michigan observed for first time. *Eos* Transactions of the American Geophysical Union, 77:337-338.

Presentations

Johengen, T.H. 2003. The role of episodic events on the transport of biogeochemically important material in Lake Michigan. Invited lecture to Grand Valley State University. October 16. Muskegon, Michigan.

Vanderploeg, H., S. Ruberg, G. Lang, T. Johengen, M. Agy and J. Liebig. 2002. Fronts and plumes as organizers of spatial distribution of nutrients and plankton in Lake Michigan. Ocean Sciences Meeting. February 11-15. Honolulu, Hawaii.

Johengen, T. 2001. The importance of episodic resuspension events on phosphorous dynamics and planktonic productivity in nearshore Lake Michigan. Invited lecture to Biology Department, University of Akron. Akron, Ohio.

Cotner, J. and B. Biddanda. 2001. Sunlight effects on bioavailability of limnetic dissolved organic matter. IAGLR. June 10-14. Green Bay, Wisconsin.

Johengen, T., J. Cotner and B. Biddanda. 2001. The impact of sediment resuspension and riverine inputs on biological productivity in the nearshore zone. IAGLR. June 10-14. Green Bay, Wisconsin.

Biddanda, B.A. 2001. Big bacterial appetite: implications for the fate of primary production in lakes and oceans. GLERL/CILER Seminar Series. May 10. Ann Arbor, Michigan.

Biddanda, B. and J. Cotner. 2001. Carbon flux through bacterioplankton in southern Lake Michigan: a large and seasonally variable fraction of primary production. ASLO. February 12-16. Albuquerque, New Mexico.

Cotner, J. and B. Biddanda. 2001. Variable role of bacterioplankton across ecosystem types. ASLO. February 12-16. Albuquerque, New Mexico.

Biddanda, B. and J. Cotner. 2000. Contribution of bacteria to planktonic biomass and respiration in lakes and ocean. ASLO Annual Meeting. June 5-9. Copenhagen, Denmark. (Invited).

Cotner, J., B. Biddanda and T. Johengen. 2000. Importance of terrestrial and other non-algal carbon sources to bacteria in large lakes. ASLO Annual Meeting. June 5-9. Copenhagen, Denmark. (Invited).

Agy, M., H. Vanderploeg and T. Johengen. 2000. A shift in mesozooplankton community structure in southern Lake Michigan. IAGLR Conference. May. Cornwall, Ontario, Canada.

Biddanda, B.A. and J.B. Cotner. 2000. DOM and sun: effect of sunlight on the bioavailability of limnetic and marine dissolved organic matter. University of Minnesota LiMNology Workshop. February 19-20. Siren, Wisconsin.

Cotner, J.B. and B.A. Biddanda. 2000. Microbes, trophic state and biogeochemical processes. University of Minnesota LiMNology Workshop. February 19-20. Siren, Wisconsin.

Cotner, J.B., B.A. Biddanda and T.H. Johengen. 1999. Bacterial production and nutrient dynamics in the Lake Michigan resuspension plume. EEGLE Workshop. October 28-30. Minneapolis, Minnesota.

Cotner, J.B. and B.A. Biddanda. 1999. Microbial mediation of C and P dynamics in large lakes and oceans. Large Lakes Observatory. October. (Invited).

Cotner, J.B. 1999. Bacteria as a constraint on productivity in lakes and oceans. Cedar Creek Summer seminar. July.

Johengen, T.H., H.A. Vanderploeg, S.A. Ruberg and G.A. Lang. 1999. Chemical and biological distributions associated with the recurrent coastal sediment plume in southern Lake Michigan. IAGLR Meeting. May 24-28. Cleveland, Ohio.

Jiang, M.S., C. Chen, D. Schwab, D. Beletsky, T. Johengen and G.L. Fahnenstiel. 1999. An ecosystem model of Great Lakes: one-dimensional experiments in Lake Michigan. ASLO Aquatics Sciences Meeting. February 1-5. Santa Fe, New Mexico.

Biddanda, B.A., M.L. Ogdahl and J.B. Cotner. 1999. Carbon flux through bacterioplankton in lakes and the ocean: regulation by system productivity. ASLO Aquatic Sciences Meeting. February 1-4. Santa Fe, New Mexico.

Cotner, J.B., T.H. Johengen and B.A. Biddanda. 1999. Rapid bacterial production in extremely cold waters stimulated by benthic-pelagic exchanges. ASLO Meeting. February 1-5. Santa Fe, New Mexico.

Cotner, J.B., T.H. Johengen and B.A. Biddanda. 1998. Microbial cycling of nutrients in the coastal plume. EEGLE Workshop. October 14-16. Ann Arbor, Michigan.

Cotner, J.B. 1998. Alterations to biogeochemical processes in lakes and oceans: important human influences. Seminar at University of Minnesota Geography Department. October. Minneapolis, Minnesota.

Biddanda, B.A. 1998. Variable carbon flux through bacterioplankton: biogeochemical implications. Seminar at University of Minnesota, Department of Ecology, Evolution, and Behavior. September. Minneapolis, Minnesota.

Cotner, J.B. 1998. Heterotrophic bacterial growth and nutrient limitation in large, oligotrophic lakes and oceans. SIL Congress. August 9-14. Dublin, Ireland.

Johengen, T.H. 1998. Overview of the Cooperative Institute for Limnology and Ecosystems Research's Task III projects. CILER Formal Review, University of Michigan. July 15-17. Ann Arbor, Michigan.

Cotner, J.B. 1998. Feedback and constraint on heterotrophic bacterial growth in aquatic ecosystems. Seminar at University of Minnesota-Duluth Biology Department. April 17. Duluth, Minnesota.

Posters

Ogdahl, M.L., B.A. Biddanda and J.B. Cotner. 2000. PicoGreen fluorometry for determination of aquatic bacterial abundance and growth. Poster at University of Minnesota LiMNology Workshop. February 19-20. Siren, Wisconsin.

Ibrahim, A. and T. Johengen. 2000. Episodic events in Great Lakes experiment: the recurrent coastal plume and its impact on distributions of phytoplankton in

Lake Michigan. Poster presentation at Summer Research Opportunity Program Symposium, University of Michigan. August. Ann Arbor, Michigan.

Mendelowtiz, J. and T. Johengen. 2000. The effects of a recurrent coastal plume on phosphorus cycling in Lake Michigan. Poster at Undergraduate Research Opportunity Program Symposium, University of Michigan. August. Ann Arbor, Michigan.

Blood, S., B.A. Biddanda and J.B. Cotner. 2000. Phosphorus availability to Lake Michigan plankton. Poster at University of Minnesota LiMNology Workshop. February 19-20. Siren, Wisconsin.

Biddanda, B.A. and J.B. Cotner. 1999. Plankton respiration and carbon flux through bacterioplankton in southern Lake Michigan. Poster at the 3rd EEGLE/KITES Workshop. October 28-30. Minneapolis, Minnesota.

Johengen, T.H. 1999. Changes in nearshore-offshore distributions of particulate matter and nutrients in Lake Michigan in response to a recurrent coastal sediment plume. Poster at the 3rd EEGLE/KITES Workshop. October 28-30. Minneapolis, Minnesota

Johengen, T. and A. Winkelman. 1999. Changes in nearshore-offshore distributions of particulate matter and nutrients in southern Lake Michigan in response to a recurrent coastal sediment plume. Poster at the 3rd EEGLE/KITES Workshop. October 28-30. Minneapolis, Minnesota.

Vanderploeg, H., S. Ruberg, G. Lang, T. Johengen, M. Agy and J. Liebig. 1999. Spatial and temporal patterns of plankton seen by the plankton survey system: does the recurrent coastal plume have an effect? Poster the at the 3rd EEGLE/KITES Workshop. October 28-30. Minneapolis, Minnesota.

Significant Interactions

There are approximately 40 principal investigators from 30 different universities, institutions, and governmental agencies collaborating on this project. Principal investigators interact through a series of annual workshops and collaborative research cruises. Workshops are held to coordinate research objectives, plan field activities, and share results. Daily interactions and information exchange are conducted through the project's web site and group mailing lists.

Thomas Johengen has served as the project coordinator for developing the field-sampling program for the biological/chemical survey cruises and has served as the chief scientist for most of these cruises.

EEGLE-KITES collaborative cruise, June 2000. We worked with Sarah Green of Michigan Technological University to examine *in situ* photo-oxidative versus biological degradation of organic matter in Lake Superior.

Collaborations within the project also supported the completion of a master's thesis by Megan Agy at the University of Michigan, the completion of a master's thesis by Paul Kovalcik at the University of Akron, and the ongoing Ph.D. dissertation of Leah Wealty at the University of Chicago.

Additional Funding

This project is financially supported by the NSF CoOp and the NOAA COP programs. In addition, the U.S. EPA has contributed greatly to the project in terms of research vessel support and the funding of collaborative research projects that enhanced the scope of the EEGLE project.

Student Participation

In addition to the students noted below, John Schampel, (M.S.) Department of Ecology, Evolution and Behavior, University of Minnesota has participated in our cruises and research activities.

Agy, Megan. 2001. M.S. School of Natural Resources and Environment, University of Michigan.

Kovalcik, Paul. 2001. M.S. Department of Biology, University of Akron.

Blood, Simba. 2000. B.S. Department of Ecology, Evolution, and Behavior, University of Minnesota.

LARGE-LAKE ECOSYSTEM STRUCTURE AND FUNCTION

In the past few decades, environmental scientists have become increasingly aware of the interwoven relationships between ecosystems and their components. Research that subscribes to this concept has been broadly defined as the "ecosystem approach." A salient aspect of limnology and the ecosystem approach is the recognition that critical materials cycle extensively through all components and trophic levels of the aquatic environment as well as between lakes, the overlying atmosphere, and adjacent land masses. Ecosystem studies of large lakes strive to examine not only the flora and fauna but also the physical and chemical environment and exchanges between land, water, and air. CILER research projects within this task, that embrace the ecosystem approach, are conducted by a cohort of physical, chemical, and biological scientists, similar to the projects in climate and large-lake dynamics and in coastal and nearshore processes. The primary distinction between large-lake ecosystem structure and function projects and other CILER projects is that the former are more focused on a specific aspect of large-lake structure and function.

CA4/IV-01: *CERCOPAGIS PENGOI*, A NEW INVADER OF LAKE MICHIGAN: FOOD WEB INTERACTIONS AND COMPETITION WITH *BYTHOTREPHES*

Co-Principal Investigators: Henry A. Vanderploeg, Great Lakes Environmental Research Laboratory and Radka Pichlova, University of Michigan

The main objective of the proposed research was to clarify the feeding biology and role of a new invader of Lake Michigan, *Cercopagis pengoi*, in a plankton food web. *Cercopagis* shares many traits in common with *Bythotrephes*, another nonindigenous predatory cladoceran that invaded the Great Lakes basin earlier and caused serious changes. Therefore, the competitive and/or predatory relations between *Cercopagis* and *Bythotrephes* will be investigated as well.

Field collections of zooplankton were made and preliminary analysis of population dynamics of *Cercopagis* suggested that *Cercopagis* has a high birth rate in all instars and it can be a significant component of the nearshore zooplankton community.

A major stumbling block to doing experimental work with *Cercopagis* — as reported by our colleagues from Russia, Baltic countries, and North America — has been the high mortality observed in collection, handling, and doing experimental work with this species. Much of our effort was focused on developing methods to collect, handle, and set up experiments without injuring the delicate *Cercopagis*. This required special collection techniques involving large cod-end reservoirs that have been used by oceanographers to aid collection of delicate zooplankton. *Cercopagis* also presents the further difficulty that its hooked and "sticky" tail spine causes the animals to stick together when collected or put in the same container. Thus, it is necessary to isolate individuals immediately after collection. By using these techniques and feeding the animals we have been able to keep them in the lab for about a week, and we expect to further refine our techniques during the upcoming

season. Thus, we believe, it is feasible to do experimental work with *Cercopagis* using careful collection and handling techniques and special but intensive care to keep them alive and healthy in the lab.

Examination of these preliminary data suggests that *Cercopagis* and *Bythotrephes* are competitors and that *Bythotrephes* preys on *Cercopagis*. We hypothesize that *Cercopagis* distribution and impacts are restricted to the drowned river mouth and nearshore region because of predation from *Bythotrephes*, which in turn may be controlled by adult alewives. Alewives and *Bythotrephes* probably structure the plankton at middle depths and offshore waters, respectively. Comparison of depth distributions of *Cercopagis* and *Bythotrephes* at a 45-m deep site during the day indicted that *Cercopagis* was found in the epilimnion, and *Bythotrephes* was found in the metalimnion. This may imply *Cercopagis* is affecting zooplankton in the epilimnion and *Bythotrephes* in the metalimnion. We have not examined nighttime distributions.

Publications

Pothoven, S.A., G.L. Fahnenstiel and H.A. Vanderploeg. 2003. Population characteristics of *Bythotrephes* in Lake Michigan. *Journal of Great Lakes Research* 29(1): 145-156.

Vanderploeg, H.A., T.F. Nalepa, D.J. Jude, E.L. Mills, K.T. Holeck, J.R. Liebig, I.A. Grigorovich and H. Ojaveer. 2002. Dispersal and ecological impacts of Ponto-Caspian species in the Great Lakes. *Can. J. Fish. Aquat. Sci.* 59:1209-1228.

Presentations

Cavaletto, J.F., H.A. Vanderploeg, M.A. Agy, G.S. Carter, R. Pichlova and S.A. Pothoven. 2003. Seasonal and annual changes in the mesozooplankton community of southern Lake Michigan. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

Vanderploeg, H.A., R. Pichlova, S.A. Pothoven, J.F. Cavaletto, G.S. Carter, D.M. Mason, T.O. Hook and E.S. Rutherford. 2003. Finding a niche in the Great Lakes: the emerging *Cercopagis* story. The 46th Conference on Great Lakes Research, International Association for Great Lakes Research and International Lake Environment Committee. June 22-26. Chicago, Illinois.

Pichlova, R., H.A. Vanderploeg, J.F. Cavaletto, and L. Stara. 2003. *Cercopagis pengoi* after three years since invasion to Lake Michigan: changes of population and impact on the food web. ASLO Aquatic Sciences Meeting. February 8-14. Salt Lake City, Utah.

Pichlova, R. and H.A. Vanderploeg. 2002. Predatory interactions by *Cercopagis pengoi*, a new invader to the Great Lakes. ASLO 2002 Summer Meeting. June 10-14. Victoria, British Columbia, Canada.

CA4/IV-02: An Effects-Based Approach to Screen for Potential Hazard of Bioaccumulated Contaminants

Principal Investigator: Peter F. Landrum, Great Lakes Environmental Research Laboratory

Summary

This project continues work begun under CILER's cooperative agreement NA67RJ0148 to investigate the challenge approach to evaluate the hazard represented by bioaccumulated contaminants. Furthermore, the study approach for this year followed on the success of last year with the demonstration, that for *Hyalella azteca*, pyrene and pentachlorobenzene (PCBZ) exhibited additive toxicity on a toxic unit basis. Thus, a challenge exposure was devised with pyrene dosed to the sediment and the PCBZ added in the overlying water to determine whether the challenge chemical could be applied in the aqueous phase. Two experimental designs were used including exposure to no light or to yellow light. These two light regimes were used to prevent photoinduced toxicity. The experiment with yellow light failed because there was an absence of bioaccumulated pyrene in the *H. azteca*. Thus, the toxicity required as expected with no accumulated pyrene was essentially the same body residues as had been required in PCBZ only exposures. Based on past work with fluoranthene, the use of white light should not cause photoinduced toxicity because the organisms should be buried in the sediment during the light phase. Thus, a third design using white light to force the *H. azteca* into the sediment was employed and showed a strong toxicity response. The total number of toxic units required for 50 percent mortality was 1.14 with exposure of 0.5 μmol g^{-1} dry wt. in sediment and 0.486 nmol L^{-1} as the PCBZ challenge.

The second area of work was to develop the time dependent response of *H. azteca* to DDE so that DDE could be used as a challenge chemical in place of PCBZ. The water-only toxicity of *H. azteca* to DDE was similar to the toxicity to PCBZ on a body residue basis. In fact, the two time-dependent curves are not different from each other. However, they are very different from the reported time dependence of polycyclic aromatic hydrocarbons. When placed on similar scales, the toxicity of DDE after about 48 h shows little time dependence while that for the PAH show significant time dependence, and the body residues to produce a toxic response are much larger for PAH.

The third area of effort was a joint experiment with fluoranthene and DDE run at Vicksberg with *Leptocherius plumulosus* exposed to sediment sorbed compounds in a factorial designed experiment. The experiment was only partly successful in that the mortality was not at the expected level in all doses. However, the DDE LR_{50} could be calculated at 0.130 (0.142-0.122) μmol g^{-1}(fw) with only DDE and 0.118 (0.129 – 0.111) μmol g^{-1}(fw) in the presence of 0.01 ± 0.002 μmol g^{-1}(fw) of PAH.

Results

Pyrene and Pentachlorobenzene Exposures. *Hyalella azteca* had previously been exposed to mixtures of pyrene and PCBZ in aqueous exposures and the result was evidence that additivity could be demonstrated on a toxic unit basis. Thus, to continue the work for evaluating benthic organisms exposed to sediments and subsequently

challenged with PCBZ, *H. azteca* were exposed to sediments containing pyrene and challenged with PCBZ in overlying water. The light regime was varied. In the dark and under yellow light there was little evidence that the method would work because the response was not different from exposures containing only PCBZ as the concentration for 50 percent mortality required 0.8 ± 0.4 toxic units (TU). This was the result of *H. azteca* failing to accumulate the pyrene. Two likely causes were investigated. The first was that the sediment bioavailability was too limited. The first sediment (approximately one percent organic carbon) was replaced with a low organic carbon sediment (0.4 percent OC), but the result was the same with very low pyrene in the organisms. The bioavailability was examined with exposure of *Lumbriculus variegatus* to the same sediment and the use of Tenax® resin extraction. Both measures exhibited good evidence of bioavailability. Thus, the problem was thought to be the light regime under which the tests were performed. It appeared that the *H. azteca* were only exposed to the overlying water particularly in the presence of PCBZ. Since *H. azteca* are negatively phototrophic, white light should encourage the organisms to stay in the sediment.

While the initial thought was to avoid white light which will force the *H. azteca* into the sediment due to the potential for photoinduced toxicity, previous studies with fluoranthene and various light regimes suggests that the toxicity of the PAH is not enhanced because the organisms stay buried in the sediment when the light is on. Thus, an experiment with two concentrations of pyrene using three concentrations of PCBZ was employed to study the challenge problem. In this case, pyrene was accumulated by the amphipods but the extent of toxicity was much greater than anticipated. Even in the absence of PCBZ there was substantial mortality. In fact, the extent of mortality was greater in these studies than previously observed in water only exposures at the same body residue levels. Water only exposures under yellow light yielded 2 d LR_{50} estimates of 4.14 μmol g^{-1}. In this study, the estimate in the absence of PCBZ was 56.6 nmol g^{-1} and between the response of *H. azteca* under fluorescent and UV enhanced light observed at 10 d exposure. This suggests that the *H. azteca* were likely experiencing photoinduced toxicity or there is some additional toxicant in the system that is not evident based on the control mortality which was greater than five percent. The estimate for the LR_{50} is not very strong because the data were either zero and near 100 percent mortality. There was no statistical difference between the estimated body residue required to produce mortality in the presence of PCBZ dosed at 250 μg L^{-1} which is likely the result of having the very high mortality. At least by using white light, *H. azteca* did accumulate pyrene and it was toxic. This experiment will need to be repeated with lower pyrene concentrations to determine whether the overall approach will work. So far we have found both ends of the spectrum. In the case of no accumulation of pyrene, the toxicity was only due to PCBZ; and in the case of high toxicity by pyrene, the amount of PCBZ required for toxicity was minimal (approximately 0.2 TU of PCBZ).

Time Dependent DDE Toxicity in H. azteca. Hyalella azteca were exposed to DDE solutions with 24 h renewal of the water concentration. As with the PCBZ, the water concentration declined during the 24 h exposure by approximately 50 percent. However, as with PCBZ, the elimination is slow 0.009 ± 0.006 h^{-1} (mean ± SD, n = 14) measured across all concentrations and all experimental time frames. This elimination rate is somewhat slower that that found for PCBZ (0.014 h^{-1}) but not

statistically different. Unlike PCBZ, the uptake rate for DDE is much faster (347 ± 88 mL g^{-1} h^{-1}) leading to much higher bioaccumulation factors 44,962 ± 23,523 where the PCBZ BCF was about 500 – 2200. There was also no apparent impact of increasing concentration on the bioaccumulation factor for DDE. The exposure range for the DDE was much lower, ranging from 0.40 to 14.1 μg L^{-1} while that for PCBZ ranged from 66.5 μg L^{-1} to 1 mg L^{-1} which reflects the relative solubility limits for the two compounds.

The body residues required for 50 percent mortality were, however, very similar for the two compounds. For DDE, as with PCBZ, the method for determining the body residue did not affect the time dependence. The temporal change in the concentration required to produce toxicity shows a steep time response. This was essentially the same temporal response found for PCBZ. Thus, both compounds are equipotent on a molar basis suggesting that they have the same mechanism of toxicity in *Hyalella azteca*. When the data is fit to the damage assessment model, it is possible to obtain an estimate for the rate of damage repair (k_r), which was found to be 0.038 h^{-1}. This rate is essentially the same as that for PCBZ. With the above data it is possible to obtain interpretation of the toxicity of DDE with any duration of exposure for *Hyalella azteca*. These data expand our ability to interpret body residue data and to better understand the impact of multiple pulsed exposures as might occur in the field.

The toxicity of DDE to *Hyalella azteca* was substantially different from previously reported temporal toxic responses to PAH congeners. The temporal response of DDE was minimal relative to that for pyrene and at long exposures the body residue values required to produce a toxic response tend to converge. Thus, if one is going to assess the toxicity of a mixture of PAH with DDE as a challenge compound in *Hyalella azteca*, then the evaluation cannot be done strictly on an additive molar basis but must be done on a toxic unit basis. If the exposures for the challenge experiment are performed within the range of 4 to 28 d exposure, then essentially DDE will exhibit a constant value for the LR_{50} against which to compare the response in the mixture.

10 d DDE and PAH Exposures in Leptocherius plumulosus. *Leptocherius plumulosus* were exposed to DDE and mixture of PAH in sediment exposures for 10 d. The experimental design was set to establish both the toxic response for DDE only and DDE in the presence of differing concentrations of PAH mixture. The LR_{50} based on measured DDE concentrations was 0.13 (0.142-0.122) μmol g^{-1} DDE. In the presence of the lowest concentration of PAH, the LR_{50} was estimated to be 0.118 (0.129 – 0.111) μmol g^{-1}(fw) DDE suggesting that the DDE contributed approximately 0.90 TU to the mixture and not significantly different than DDE only exposures.

The measured concentration of PAH in the organisms was 0.01 ± 0.002 μmol g^{-1} measured as the sum of PAH. Assuming that all the PAH were as sensitive as fluoranthene, the number of TU represented by the PAH would be 0.04. Thus, the toxicity was largely contributed by the DDE. Therefore, it is clear that PAH accumulation was limited and did not contribute significantly to the toxic response.

Publications

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Additional Funding

This work was funded in part by the U.S. Army Corps of Engineers.

CA4/IV-04: Post-Depositional Sediment Mobility of Biogeochemically Important Materials in Lake Michigan

Co-Principal Investigators: Brian J. Eadie, Great Lakes Environmental Research Laboratory; John A. Robbins, Great Lakes Environmental Research Laboratory; and Thomas H. Johengen, University of Michigan

In aquatic systems, rapid and efficient sorption and settling remove contaminants from the water column resulting in large inventories in near-surface sediments.

During the decades that these materials are part of the resuspendable pool, they constitute a major non-point source of nutrients and contaminants to the water column and biota. The materials in these transient reservoirs are biogeochemically transformed within the lake, then redistributed throughout the year by a spectrum of energetic events. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades presently results in much greater fluxes to the water column than from all external inputs. The focus of this effort is to measure concentrations, inventories, and fluxes of various chemical constituents (including carbon, nutrients, and quasi-conservative tracers) in Lake Michigan sediments and settling particles, and use these data in models of lake-scale mass balance models.

The goal of this project was to complete all chemical analyses of trap and sediment samples and composites previously collected under other CILER projects, EEGLE and the Lake Michigan Mass Balance study, and to conduct QA/QC on the overall database. All of the laboratory analyses were completed and the data are currently being investigated and prepared for publication. Preliminary interpretation of the data clearly shows very different sediment environments in the northern and southern basins of Lake Michigan. Concentrations of biogenic silica are much higher in the north, a somewhat surprising result since primary productivity is believed to be higher in the southern basin where most of the river input of nutrients is concentrated.

Publications

A major report containing all of the radiochemical data and some nutrient data is in its final stage of preparation and will serve as a background for at least four peer-reviewed manuscripts.

Presentations

Eadie, B.J., M.B. Lansing, A.G. Winkelman and B. Giroux. 2002 Basin-scale productivity response to large sediment resuspension events in southern Lake Michigan. Ocean Sciences Meeting. February 11-15. Honolulu, Hawaii.

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Eadie, B.J., J.A. Robbins, D.J. Schwab, P. Van Hoof, K. Hornbuckle and T.H. Johengen. 2001. Advances in our understanding of sediment-water exchange and sediment transport from the Lake Michigan Mass Balance and Episodic Events Programs. Lake Michigan – State of the Lake Conference. November 6-7. Muskegon, Michigan.

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Significant Interactions

This work was part of a large interagency program with cooperation among U.S. EPA-GLNPO, NOAA-GLERL, U.S. Geological Service, Michigan DNR, and the Wisconsin DNR. All of these groups had responsibilities for portions of the sample collection and analyses for a complete mass balance of several chemicals in Lake Michigan. This is a National Demonstration Program under the Clean Air Act.

Additional Funding

Funding was provided by NOAA-GLERL and U.S. EPA-GLNPO to conduct work associated with this project.

CA4/IV-05: Implications of Cercopagis and Bythotrephes to Alewife Recruitment and Stability of the Lake Michigan Pelagic Food Web

Principal Investigator: Henry Vanderploeg, Great Lakes Environmental Research Laboratory; Doran Mason, Great Lakes Environmental Research Laboratory and Thomas H. Johengen, University of Michigan

Summary

We propose to develop a general model from experimental observations of prey selection and feeding for the invading predatory cercopagid cladocerans *Cercopagis pengoi* and *Bythotrephes longimanus* (Figure 1) that will be useful for predicting

predatory impact of these cercopagids. We will combine this information along with field observations of population dynamics, production and spatial distribution of zooplankton and fishes collected in this and related projects to describe and understand invasion dynamics of *Cercopagis* and determine if these cercopagids have disrupted the Lake Michigan food web. We hypothesize that alewife predation on *Bythotrephes*, a competitor and predator of *Cercopagis* (this study), has allowed *Cercopagis* to invade nearshore waters of the spatially complex Lake Michigan. We are also examining whether both these cercopagids have created a bottleneck for recruitment of young of year alewife and other fishes. In a new approach, we are exploring the use of sequential sediment traps to define population dynamics of cercopagids, including proportion killed by fish predation. Work in CY 2004 will focus on spatial distribution and predatory interactions among zooplankton, *Bythotrephes*, *Cercopagis*, *Mysis*, and Y0Y and adult alewives.

Scientific Rationale

Radka Pichlová (supported on a related project sponsored by the Great Lakes Fishery Commission) and Henry Vanderploeg have been doing experimental work on food web interactions of the Ponto-Caspian predatory cladoceran *Cercopagis*, which invaded Lake Michigan in 1999, and competition and predatory interactions with *Bythotrephes*, a larger predatory cercopagid of Palaearctic origin that invaded Lake Michigan in 1985 (Figure 1). It is of great importance to invasion theory how *Cercopagis*, so very similar to the already established *Bythotrephes*, found a "niche" in Lake Michigan. The major concern about both species of cercopagids is that they may compete with small fishes such as larval and young of year (YOY) alewife and perch for zooplankton (Figure 2) (Francis et al, 1996; Vanderploeg et al, 2002). The tail spine of both cercopagids (Figure 1) foils predation by small fishes; however, cercopagids may be preferred prey of large fishes (Figure 2) (Vanderploeg et al, 2002). Because cercopagids have high reproductive output, high feeding rates and can prey on cladocerans large relative to their body size, they could be serious competitors with larval and small fishes (Figure 2).

Progress

We carried out an ambitious field monitoring and experimental program to examine population dynamics of the newly invading *Cercopagis* on alewife recruitment and the pelagic food web of Lake Michigan. The project extended our field monitoring activities started in EEGLE and a study of alewife recruitment carried out by Doran Mason (Great Lakes Environmental Research Laboratory) and Ed Rutherford (University of Michigan). Field sampling at M110, M45, M15, and C (Muskegon Lake) for nutrients, chlorophyll and zooplankton was completed in March through December in 2002 and 2003, with monthly collections during spring and fall and biweekly during the summer. These collections supported our long-term time series to examine post-invasion population dynamics of the two cercopagids. We will explore use of the egg ratio to examine birth rates of the prey of the cercopagids. Usefulness of this approach depends on how well the preserved zooplankton retained their eggs. This analysis will be done at the time we measure zooplankton lengths for biomass determinations. Many of the zooplankton collections have been counted but few have been sized. Egg ratios, spine lengths, and biomass of the

cercopagids have been determined for 2000-2002; therefore, these measurements need to be done for 2003 and 2004.

We made good progress in both experimental (see presentation titles by Vanderploeg et al, Pichlová et al, Cavaletto et al, and Carter et al for ASLO and IAGLR) and fieldwork, including carrying out the fieldwork necessary for a study of spatial distribution of zooplankton and alewives and feeding preferences of alewives as they relate to *Cercopagis* and *Bythotrephes* abundance. The spatial and field study will be very important for understanding how *Cercopagis* found a niche in Lake Michigan and the role of alewives in creating this niche.

To examine potential food-web impacts and interactions, Radka Pichlová has been doing experiments in large bottles and small enclosures to determine prey selection and feeding rates of *Cercopagis* and *Bythotrephes* on different Great Lakes zooplankton, predatory interactions among *Bythotrephes*, *Cercopagis*, and *Leptodora* (a native predatory cladoceran). Preliminary results show that *Cercopagis* prefers smaller prey than *Bythotrephes*. For example, she showed *Cercopagis* would eat small zooplankton such as copepod nauplii, *Bosmina*, and zebra mussel larvae. Although much has been done, much more work on prey selectivity and functional response to prey concentration remains for both species. Preliminary insights into feeding mechanisms were obtained by direct observation with video: *Cercopagis* are slower than *Bythotrephes* and thus may be less adept at capturing quick, agile prey like copepods.

In 2001 and 2002 Doran Mason and colleagues (the larval fish team) carried out a field project of extensive sampling of zooplankton and larval fishes, May through October, in Muskegon Lake and in nearshore and offshore regions of Lake Michigan in support of the research grant "Dynamics of Alewife Recruitment Variability in Lake Michigan" (PI's: Edward Rutherford, University of Michigan; Doran Mason, Great Lakes Environmental Research Laboratory; Charles Madenjian, USGS Great Lakes Science Center; and William Patterson, Syracuse University). The larval fish team is examining the role of drowned river mouths such as Muskegon Lake in comparison with nearshore and offshore Lake Michigan for supporting alewife recruitment. In theory, the warm, nutrient- and zooplankton-rich drowned river mouths should support enhanced growth and survival of larval and YOY alewives relative to Lake Michigan proper.

To understand invasion dynamics and document impacts of *Cercopagis* on alewife recruitment, the zooplankton team (Vanderploeg, Cavaletto, Pichlova, and a summer fellow) examined zooplankton samples collected summer and fall of 2001 and March through December in both 2002 and 2003 (biweekly during summer, monthly at other times) from station C, the deepest site in Muskegon Lake, along with samples from M110, M45, M15, the stations on 110-m, 45-m, and 15-m contours of the onshore offshore transect in Lake Michigan at Muskegon, where we have records from a previously funded CILER project, "Changes in the Pelagic Food Web of Southern Lake Michigan (CPFWSLM)," EEGLE and the GLERL monitoring projects.

Although much more work needs to be done on spatial and temporal distribution of zooplankton and feeding interactions of *Cercopagis* and *Bythotrephes*, examination of these preliminary data suggest that *Cercopagis* and *Bythotrephes* are

competitors and that *Bythotrephes* preys on *Cercopagis*. We hypothesized that *Cercopagis* distribution and impacts are restricted to the drowned river mouth and nearshore region because of predation from *Bythotrephes*, which in turn may be controlled by adult alewives, since *Bythotrephes* are favored prey of alewives. Alewives and *Bythotrephes* probably structure the plankton at middle depths and offshore waters, respectively. Another factor we are beginning to consider is the role of *Mysis* in altering alewife and cercopagid interactions. Preliminary diet analysis of daytime samples suggests that *Mysis* and *Bythotrephes* are the preferred prey of alewives and that *Cercopagis* is rarely eaten. In deep waters where *Mysis* is abundant, predation pressure may be released on *Bythotrephes*. We are now examining the diet and prey selection of adult and YOY alewives for *Cercopagis*, *Bythotrephes*, *Mysis* and other zooplankton using fish collected in early September 2003 in midwater trawls at night and bottom trawls during day. We are very happy to have collected fish in the midwater trawl, as this can be a difficult feat. These collections of fish were matched with acoustics for their spatial distribution and with zooplankton net tows collected in three depth ranges: epilimnion, metalimnion, hypolimnion.

Whether *Cercopagis*, *Bythotrephes*, or their prey is seriously depleted by predation depends on predation rate relative to birth rate. Birth rate is affected by food quantity and quality (bottom up effects). We can use the egg-ratio method to estimate population growth rates and to identify areas of high population growth (Muskegon Lake vs. Lake Michigan) for *Cercopagis*, *Bythotrephes*, and other cladocerans (the prey). These estimates of population growth can be compared to estimates of mortality imposed by *Cercopagis*, *Bythotrephes*, and alewives to determine significance of the mortality imposed by predation.

To understand the significance of bottom-up effects of P limitation on planktonic biomass and quality of seston as food for herbivorous zooplankton population growth (reflected in their egg ratios) in these different regions, we measured size-fractioned chlorophyll, total P and seston C:N:P ratios (an indicator of nutritional deficiency of P).

In 2002, the larval fish team finished zooplankton and larval fish sampling in Muskegon Lake and in Lake Michigan to determine the spatial distribution, abundance and diet of first year alewife. The two teams in 2002 and 2003 collaborated to explore simultaneous towing the plankton survey system and 120 KHz split beam acoustic fish to determine vertical distributions of physical variables, chlorophyll fluorescence, zooplankton and larval, juvenile, and adult alewives along a transect through Muskegon Lake to offshore Lake Michigan. All sensors were calibrated with appropriate collections of chlorophyll, zooplankton, and fishes. Vertical profiles of chlorophyll and nutrients were determined at all master stations, and vertical profiles of zooplankton determined by opening closing nets occasionally were determined. The standard limnological variables were successfully collected; however, there were problems in use of the acoustics equipment in both 2002 and 2003 because of faulty equipment and inexperienced operators.

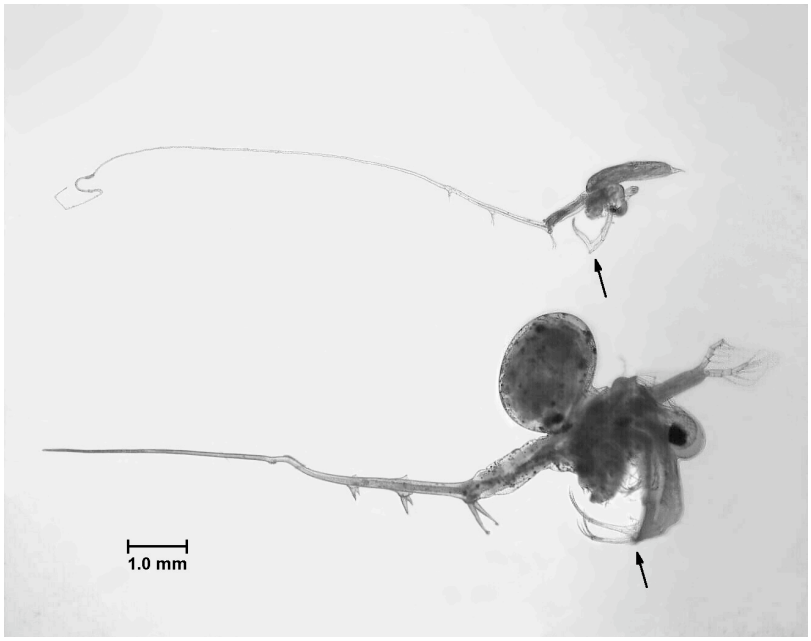

Figure 1. Contrast between morphology and size of *Cercopagis pengoi* (upper) and *Bythotrephes cederstroemi* (lower) collected in Lake Michigan July-August, 2000, in waters of 45-m depth off Muskegon, Michigan. Arrows point to the first thoracopods, which putatively would be important for grasping and holding large prey.

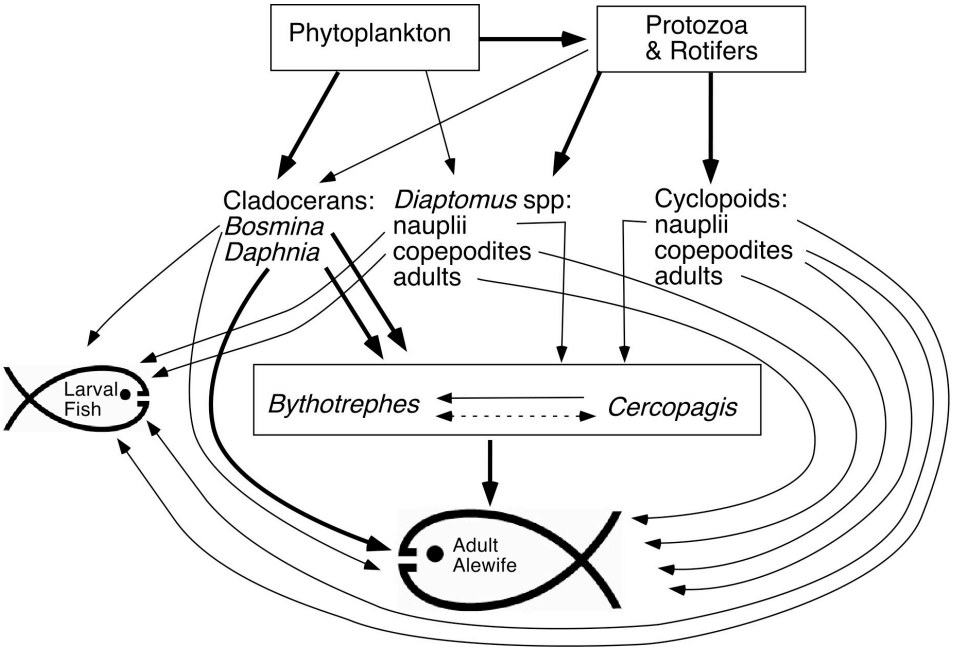

Figure 2. *Bythotrephes cederstroemi* and *Cercopagis pengoi* in the epilimnetic food webs of Great Lakes and their connection to important epilimnetic forage fishes, which would be alewives in Lake Michigan. Thick arrows indicate high selectivities of the consumer and thin arrows indicate low selectivities. We anticipate that *Cercopagis* would prefer smaller cladocerans (*Bosmina*) than would *Bythotrephes*, and that *Cercopagis* could be prey of *Bythotrephes*. The dotted line with two arrowheads on it implies potential competitive interactions because of similar diet preferences.

Presentations

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CA4/IV-06: Status and Trends of Benthic Macroinvertebrates in Lake Michigan

Principal Investigator: Thomas F. Nalepa, Great Lakes Environmental Research Laboratory

Benthic samples were collected in Lake Michigan from 1998 through 2002 to determine long-term trends in the major benthic macroinvertebrate taxa. Of special interest was density trends in *Diporeia, Dreissena polymorpha* (zebra mussel), and

Dreissena bugensis (quagga mussel). Sampling occurred mainly at 40 sites in the southern basin that were sampled in 1980-81, 1986-87, and 1992-93. In 2000, samples were also collected at 160 sites located throughout the lake. Many of these sites were also sampled in 1994-95. A number of significant changes in benthic populations were documented. *Diporeia* populations, which first started to decline in the southeast portion of the lake in 1992, continued to decline. Declines were evident not only in the southern basin but also throughout the lake. Between 1994-95 and 2000, lakewide declines were 71 percent, 84 percent, 60 percent, and 44 percent at sites in the less than 30 m, 31-50 m, 51-90 m, and greater than 90 m depth intervals, respectively. *Diporeia* was totally absent or rare to depths of 50 m from near Chicago to Grand Haven in the southeastern end, and to depths of 50 m in the area north of Frankfurt-Sturgeon Bay, which includes Green Bay and Grand Traverse Bay. Over this same time period, the zebra mussel population expanded, with greatest density increases occurring at 31-50 m. Furthermore, densities of quagga mussels also increased. This species is now almost as abundant as zebra mussels in some locations. The expected expansion of the quagga mussel population will likely lead to further declines in *Diporeia*. Since *Diporeia* is an important fish food item, the continued loss of this amphipod will likely lead to further changes in the upper food web.

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Significant Interactions

This project interacted with the U.S. EPA Great Lakes National Program Office which provided use of the *R/V Lake Guardian*, and the USGS Great Lakes Science Center which provided help in collecting quagga mussels from shoal areas in the northern portion of the lake.

CA4/IV-07: Protocol Development for Monitoring Great Lakes Wetlands

Principal Investigator: Stephen Lozano, Great Lakes Environmental Research Laboratory

Project Rationale

Great Lakes wetlands perform many important functions in the aquatic habitat. They are complex ecosystems that support high biological productivity, dynamic exchanges of nutrients between land and water, and play crucial roles in shoreline stabilization and protection. Urban development has resulted in the degradation of many of our wetlands and near coastal waters and loss of critical ecosystem and economic functions. Under the Coastal Zone Management Act of 1972, a program was established for the restoration of coastal habitats across the United States and its territories, stressing a comprehensive approach to maximizing benefits derived from projects. Under the Estuarine Restoration Act, an estuary is defined as the part of a river or stream or other body of water that has an unimpaired connection with the open sea and where the seawater is measurably diluted with fresh water derived from land drainage. The term was broadened, however, to include near coastal waters and wetlands of the Great Lakes that are similar in form and function to estuaries, including the area located in the Great Lakes biogeographic region and designated as a National Estuarine Research Reserve under the Coastal Zone Management Act of 1972 (this is Old Woman Creek Reserve).

Estuary habitats include the physical, biological, and chemical elements associated with an estuary, including the complex of physical and hydrologic features and living organisms within the estuary and associated ecosystems. Restoration of estuary habitat includes those activities that result in improving degraded estuaries or estuary habitat or creating newestuary habitat (including both physical and functional restoration), with the goal of attaining a self-sustaining system integrated into the surrounding landscape.

This research project is designed to determine the important ecosystem structures and functions of Great Lakes wetlands that must be protected when developing the monitoring protocols and standards for all future research projects that fall under the Estuary Restoration Act. It is anticipated that even given the diversity of habitats to potentially be restored and the extreme latitudinal range across which these habitats occur, there are consistent principles and approaches that form a common basis for effective monitoring, regardless of the habitat considered. This research will provide a quantitative basis for assessing the impact of a restoration project and will assist in the development and implementation of monitoring plans for projects potentially occurring in any or all of these habitats. Based on the research conducted within this project, the impact of a restoration initiative, both positive and potentially negative, may be quantified.

Background

An estuary is a semi-enclosed body of water in which there is a measurable mixing of salt and fresh water. The mixing of fresh and salt water that unites these geographic features is a result of the estuary's interconnection with adjacent ecosystems and creates an environment highly variable in terms of salinity, nutrients, water levels, and temperature. Numerous species of plants and animals

that can tolerate the range of physical and chemical characteristics thrive in these habitats. Estuaries as a whole are highly dependent on inputs, including surface and subsurface freshwater, atmospheric exchange and deposition, and movements of salt water and organisms from adjacent ocean waters. Estuaries also export significant amounts of material, contributing low salinity water, organic material, organisms, and nutrients to nearshore waters. Estuaries are among the most productive ecosystems on earth. Bay and estuarine systems directly or indirectly support some of the most profitable fisheries, as well as provide habitat, food, and resting places for numerous endangered and recreationally important species. In fact, in some coastal areas, estuarine-dependent species comprise 70 to 90 percent of the fish and shellfish commercial landings.

Despite the importance of estuaries for their support of healthy natural ecosystems and regional economies, estuaries throughout the U.S. are in a state of decline. While the reasons for decline are as varied as the systems themselves, human impacts are consistently a primary or contributing factor. Physical and hydrologic modification of coastal areas for development, agriculture, and industry have directly removed productive habitat and shoreline buffer areas that are essential to protecting estuaries from upland runoff and other associated activities. Runoff and point sources have contaminated sediment and organisms, as well as resulting in an over enrichment and eutrophication of coastal waters. Critical function within these productive estuarine habitats has been impaired or lost entirely. This impairment has resulted in reduced value to the user communities in areas surrounding the estuary. Fortunately, what has been lost or impaired can, in many cases, be restored.

Coastal restoration is the process of reestablishing a self-sustaining habitat that, in time, can come to resemble a natural condition in terms of structure and function. Fully functioning restored systems are resilient, self-sustainable, and produce a quantity and diversity of organisms of similar composition to natural or reference systems. Part of this full functionality includes structural components such as a certain minimum level of water quality; sediment that is not contaminated, appropriate grain sizes; hydrodynamics that allow for removal or dilution of wastes/pollutants and colonization or dispersal of new recruits; and an abundance and diversity of flora and fauna similar to natural systems. Because of the recognized need for coastal restoration, programs have been established across the country to conduct restoration planning and design and build projects in specific bay systems. Nation-wide programs are much less common.

Work Plan

This research activity supports CILER's research theme on coastal and nearshore processes and ecosystem structure and function. We propose to document the links between nearshore and coastal zones and Great Lakes wetlands and provide new insights into the importance that wetlands play in preserving the ecosystem integrity of coastal and nearshore waters of the Great Lakes. This research will be useful for developing plans for conserving and restoring coastal estuaries and its critical habitats. Furthermore, it will provide a foundation for future wetland studies that will directly address land-water nutrient exchange, cycling of contaminants and

nutrients, and the exchange of biota between the nearshore zone and open lake. We are currently conducting the following activities to advance our objectives.

- Review of literature and interview scientists for understanding the role of different coastal habitats in preserving the integrity of Great Lakes water quality.
- Review literature and develop lists of structural and functional characteristics of identified Great Lakes coastal habitats that should be evaluated in any restoration plan, denoting those that are critical as restoration success metrics.
- Review literature and document the role of sediment characteristics including level of contamination, grain sizes and total organic carbon in preserving the integrity of Great Lakes water quality.
- Review literature and document the role that the hydrodynamic conditions allow for removal or dilution of wastes/pollutants and colonization or dispersal of new non-indigenous recruits to Great Lakes wetlands.

CA4/IV-08: Assessment of in situ Early Diagenesis of Organic Geochemical Proxies Employed in the Great Lakes Paleoenvironmental Reconstructions

Principal Investigators: Philip Meyer, University of Michigan and Brian J. Eadie, Great Lakes Environmental Research Laboratory

Background

Organic matter components of sediments constitute an important part of the fossil record used to reconstruct environments of the past. Sedimentary organic matter provides evidence of past biota and former environmental conditions in its molecular, isotopic, and elemental composition (e.g., Meyers, 1997). The amounts and types of organic matter in sediments thereby contribute in significant ways to paleoenvironmental and paleoclimatological records and reconstructions. Biomarker molecules, in particular, are especially informative as "geochemical fossils".

However, only a small fraction of the original amount of biosynthesized organic matter survives to become part of the sedimentary record of past environments (e.g., Eadie et al, 1984). Alteration and destruction of organic matter occurs during sinking and is particularly severe in the upper few centimeters of sediments (e.g., Hodell and Schelske, 1998). Degradation rates of the various components of organic matter differ among the range of molecular types that comprise this material and lead to selective diagenetic losses (e.g., Goossens et al, 1989; Meyers and Eadie, 1994). In addition, sediment microbes synthesize new components that partially replaces the organic matter that is initially deposited.

A critical question in view of the known changes that occur to the amount and character of sedimenting organic matter is "How accurately does the organic matter in sediments reflect the original sources and environmental conditions?". In order to reconstruct paleoenvironments more accurately, assessment of the amount of early diagenetic alteration of the isotopic and biomarker compositions of sediment organic matter is needed. Such knowledge will enable interpretive corrections for the probable modifications of the organic geochemical paleo-environmental information available in sediments.

Rationale

This project builds upon activities and collaborations established under a CILER Science Enchancement project (CA4/I-07SE: Molecular and Isotopic Paleo-temperature Proxies in the Great Lakes Sediments: Keys to Climate Projection? - see pp. 9-11 of this report). For this extended project, we will attempt to quantify the extent of early diagenetic alterations to sedimentary isotopic and molecular records so that organic geochemical paleoenvironmental reconstructions can be created with minimal diagenetic skewing. It will compare molecular distributions of biomarker-type compounds in sediment samples from the same age horizons collected 21 years apart from the same location. This is a novel and unprecedented opportunity to assess *in situ* diagenesis by analyzing the same sediment horizon under natural burial conditions. The study will be sited in Lake Erie, where elevated sedimentation rates provide the highest resolution in the Great Lakes (approximately two years). Sediments ranging in age from modern to about 100 years old will be studied to assess possible continuing impacts of longer term diagenesis. Compounds that will be studied are straight- and branched-chain alkanes, which will be used as representatives of biomarkers having low susceptibility to alteration; straight-chain alkanols, which are representatives of moderately reactive molecules; and carboxylic acids, which represent relatively reactive and thus more readily altered biomarker molecules. These analyses will be done against a backdrop of the well-documented changes in algal productivity and organic matter delivery that will provide a rigorous evaluation of the robustness of the Lake Erie biomarker proxy record.

Samples and Procedures

The Lake Erie Eastern Basin Reference Site will provide the high-resolution sediment cores that constitute the most critical element needed for the success of our project. A core obtained at this location in 1981 has been dated by ^{210}Pb analysis. The 1.4 m core spans 90 years of sedimentation history, and its sharp ^{137}Cs peak shows that mixing has not jeopardized its exceptional time resolution. The core has been divided into 1-cm intervals that approximate sub-annual to annual periods of sediment accumulation. These intervals have been stored frozen since collection to protect their biomarker molecule contents from microbial degradation. We will obtain new cores during September 2002 from the Eastern Basin Reference Site. One core will be dedicated to comparison of the organic matter that has resided in the lake bottom since 1981 with that of the core that has been "frozen in time" to evaluate the effects of *in situ* early diagenesis. Several same-age sediment horizons from multiple new cores will be compared to assess natural variability in organic geochemical compositions so that robust statistical treatment of our analytical results can be done.

$CaCO_3$ contents will be determined by treatment of dried core samples with dilute HCl to release CO_2 from carbonate minerals in a carbonate bomb apparatus in the Organic Geochemistry Laboratory at the University of Michigan. The carbonate-free residue remaining after the carbonate bomb determination will be analyzed using a Carlo Erba 1500 CHN analyzer. This procedure yields organic carbon concentrations and organic C/N ratios. Organic matter $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios of the carbonate-free samples will be measured at the Great Lakes Environmental Laboratory using a VG PRISM mass spectrometer.

Extraction of biomarker molecules will be done in the Organic Geochemistry Laboratory at the University of Michigan. Biomarkers will be isolated by extraction with double-distilled dichloromethane using sonication. Extracted geolipids will be treated with methanolic-boron-trifluoride to convert fatty acids into their methyl esters prior to separation into subfractions. Extracts will be separated into geolipid subfractions (saturated and monounsaturated hydrocarbons, aromatic and polyunsaturated hydrocarbons, carboxylic acids, alkanols and sterols, long-chain ketones) by silica gel column chromatography. The alkanols will be converted to their trimethylsilyl derivatives with BSTFA prior to gas chromatographic analysis.

The alkane, alkanol, and fatty acid biomarker subfractions will be analyzed by gas chromatography using capillary columns in a Hewlett Packard 5890-II coupled with a Hewlett Packard ChemStation data system and equipped with a FID detector and an on-column injector system. A Hewlett Packard 5890 capillary gas chromatograph with an MSD detector is also available for use in this project at the Great Lakes Environmental Laboratory.

Progress

Progress to date for this project is previously described under the Science Enhancement project CA4/I-07SE.

Future Activities

The research we describe in this project is an expression of our continuing interest in understanding how organic matter is produced, delivered, and preserved in the sediments of the Great Lakes. It also forms part of our long-term plans to investigate the history of natural and anthropogenic paleoenvironmental changes in the Great Lakes region. After we have assessed the organic geochemical integrity of paleoenvironmental proxies from our comparison of the century-long Lake Erie cores, we plan to explore longer periods of deposition history and, in particular, transitions into and out of the Little Ice Age over the past millennium. In addition, we wish to test applications of compound-specific isotopic compositions of organic molecules to identify product-precursor relations in paleoenvironmental proxies in Great Lake sedimentary records. These goals will be the basis of future proposals to the NOAA Office of Global Change Program and the NSF Earth System History Program.

Student Participation

This research project will constitute part of the dissertation research of Christina Knowlton, a Ph.D. student in the Department of Geological Sciences at the University of Michigan who wishes to use sedimentary geochemical evidence to reconstruct the history of environmental changes in the Great Lakes region.

CA4/IV-09: Ecology of Lake Whitefish Responses to Changes in Benthic Communities in Lake Huron

Principal Investigator: Thomas Nalepa, Great Lakes Environmental Research Laboratory

Research Rationale and Plan

The benthic amphipod *Diporeia* is the dominant benthic macroinvertebrate in offshore waters of the Great Lakes (greater than 70 percent of total benthic biomass at depths greater than 30 m) and serves as a major trophic link between pelagic productivity and fish. As a detritivore, this glacial-relict amphipod ingests organic material settled from the water column (mainly diatoms) and, in turn, is fed upon by most species of fish. Because of this ecosystem role, *Diporeia* is considered a keystone organism in the movement of energy between trophic levels in the offshore zone. Recently, densities of *Diporeia* have declined in Lakes Michigan, Erie, and Ontario, and large areas are now completely devoid of this organism (Dermott and Kerec 1997; Nalepa et al, 1998; Lozano et al, 2001). While exact causes of the decline in *Diporeia* are still not clear, in each of the lakes the decline was coincident with the establishment and spread of the zebra mussel, *Dreissena polymorpha.*

Recent studies suggest that the decline in *Diporeia* is leading to decreases in the condition and growth of fish species that heavily depend upon it as a source of food. For instance, in Lake Michigan declines in lake whitefish condition were noted soon after populations of *Diporeia* decreased (Pothoven et al, 2001). With few *Diporeia* present, the fish fed on low-quality food items such as zebra mussels and sphaeriids. Similar declines in lake whitefish condition were reported in Lake Ontario after *Diporeia* populations decreased (Hoyle et al, 1999).

Although we know that *Diporeia* is declining in Lake Huron (Nalepa unpublished), little is known about the corresponding responses of lake whitefish in the lake. This fish species is the most important commercial fish in Lake Huron. Harvest in the lake is approximately 4 million pounds per year, which is more than the total of the sport and commercial harvest of all other species combined. A decline in condition would have economic implications as harvest and marketability will decrease. Lake whitefish in poor condition could also experience poor reproductive success, causing a decline in recruitment to the fishery. Understanding diet patterns and bioenergetics of lake whitefish in Lake Huron was recently identified as a top-priority research item for funding by the Lake Huron Technical Committee, under the auspices of the Great Lakes Fishery Commission.

We propose to examine the seasonal depth distribution and diet of lake whitefish in Lake Huron off Alpena, Michigan. Lake whitefish will be collected at two to three stations in water depths 15-75 m in spring, summer, and fall. Fish will be collected using multi-panel monofilament gill nets (square mesh size 2-5.5 inch) set on the bottom overnight. All fish collected will be measured, weighed, a scale sample will be taken for age analyses and the stomach will be removed and frozen. The fish body will be retained for caloric density analyses. In the laboratory, stomachs will be dissected and prey items identified and counted. Prey lengths of whole organisms will be measured using a computer image analysis system (Image-Pro 3.0). Prey length will be converted to dry mass using length-weight regressions or species-specific mean weights. Diet will be reported as frequency of occurrence (percent of fish containing a given prey type), and percent of the total calculated

dry-weight. Benthic invertebrates will be collected at the same sites as the fish collections. All organisms will be picked and counted and the size of *Diporeia* will be determined.

In addition to examining fish collected off Alpena, we have been offered the opportunity to examine the diet of lake whitefish collected from other areas of Lake Huron. As part of their whitefish assessment programs, the Ontario Ministry of Natural Resources (Lloyd Mohr is contact) regularly collects fish along the eastern shoreline (Ontario waters), and the Michigan Department of Natural Resources (Jim Johnson is contact) collects fish along the western shoreline (Michigan waters). These agencies will provide the fish, and we will measure the same variables as for fish collected off Alpena. Benthic invertebrate samples will be collected at the same sites where the fish were collected. We thus will have information on lake whitefish diet and condition from areas with varying densities of *Diporeia.*

Accomplishments

Determine the Rate of Diporeia Decline. Prior to this project, in 2000 we conducted a benthic survey in the main basin of Lake Huron to document densities of *Diporeia* and other macroinvertebrates. Although spatial coverage was good, with 66 sites sampled lake-wide, no sites were located in Georgian Bay or North Channel. To accomplish the goal of complete lake coverage, arrangements were made with Environment Canada to collect benthos samples in Georgian Bay and North Channel during their surveillance cruise in August 2002. During this cruise, benthos samples were collected in triplicate at 17 sites in Georgian Bay and at 13 sites in North Channel. Over this reporting period, all organisms in these samples were picked, sorted by major taxa, and counted. To examine population trends of *Diporeia* in these two lake areas, densities found in 2002 were compared to densities found in 1973 (Loveridge and Cook, 1976). The 1973 survey was the most recent survey conducted in Georgian Bay and North Channel prior to our sampling in 2002. Overall, densities of *Diporeia* in 2002 were similar to, or greater than, densities found in 1973 (Table 1). The only exception was at the 31-50 m depth interval in North Channel where *Diporeia* densities were lower. Thus, based on these data, *Diporeia* populations appear to be stable in both Georgian Bay and North Channel. This finding contrasts to trends found in the main basin. The 2000 survey showed that densities of *Diporeia* in shallower areas of the main basin (less than 50 m water depth) were significantly lower than densities found in 1972, and that *Diporeia* was no longer present in the southern portion of the lake (Nalepa, unpublished data).

Depth Interval	Georgian Bay		North Channel	
	1973	2002	1973	2002
< 30 m	771 ± 286 (17)	1,690 ± 827 (3)	1,645 ± 248 (23)	2,054 ± 705 (5)
31-50 m	1,579 ± 278 (24)	1,456 ± 595 (5)	2,593 ± 2,134 (23)	892 ± 401 (6)
51-90 m	1,774 ± 137 (52)	1,684 ± 306 (9)	3,068 ± 513 (7)	3,348 ± 43 (2)

Table 1. Mean (± SE) density (No./m^2) of *Diporeia* at various depth intervals in Georgian Bay and North Channel, Lake Huron in 1973 and 2002. The 1973 data was taken from Loveridge and Cook (1976). The number of sampling stations is given in parenthesis.

In addition to processing samples collected throughout Georgian Bay and North Channel in August 2002, we also counted, picked, and sorted benthic organisms in samples provided by the Ontario Ministry of Natural Resources (OMNR) as part of their ecosystem monitoring program. The program was initiated in 2000 with the purpose of monitoring trends in major food web components, including benthic macroinvertebrates. Each year, benthic samples were collected at various depths (20, 40, 60, 80, 90-100 m) along a transect near Cape Rich, which is on the southern shoreline of Georgian Bay. Densities of the major benthic taxa in 2000-2002 are given in Table 2. Of concern is the obvious decline in *Diporeia* at all depths over this period. Densities found at the Cape Rich transect in 2002 were far lower than mean densities found at other sites of similar depth (see Table 1). Reasons for this discrepancy are not clear at this time, but population declines can be very localized (Nalepa et al. 1998).

Depth (meters) and Year	Taxa							
	Diporeia	Oligochaeta	Chirono-midae	Sphaeri-idae	Gastropoda	*Hexagenia*	*Dreissena polymorpha*	*Dreissena bugensis*
20 m								
2000	315	2794	210	486	10	277	2241	0
2001	38	601	181	286	0	734	191	0
2002	19	686	114	67	76	982	1649	48
40 m								
2000	1144	467	67	153	0	0	0	0
2001	1516	277	219	372	0	0	10	0
2002	524	477	67	572	0	0	10	0
60 m								
2000	2174	2136	105	0	0	0	10	0
2001	791	524	0	10	0	0	0	0
2002	48	524	38	19	0	0	0	0
80 m								
2000	1805	992	219	0	0	0	0	0
2001	1468	86	68	124	0	0	0	0
2002	86	324	29	86	0	0	0	0
92-100 m								
2000	1707	734	248	76	0	0	0	0
2001	1182	744	68	343	0	0	0	0
2002	114	896	0	143	0	0	0	0

Table 2. Mean density (No./m^2; n=2) of major macroinvertebrate taxa in 2000-2002 at various depths along a transect off Cape Rich, Ontario, southern shoreline of Georgian Bay.

Examine Diet Patterns in Lake Whitefish. To supplement our examination of seasonal changes in diet patterns of lake whitefish off Alpena, Michigan, additional fish were obtained from the Michigan Department of Natural Resources (MDNR), U.S. Fish and Wildlife Service (USFWS) and OMNR that were collected in 2002. The former two agencies provided fish that were collected along the Michigan shoreline north of Alpena, Michigan, while the latter agency provided fish from the Canadian shoreline south of Goderich, Ontario and in Georgian Bay (Cape Rich transect as given above). This project proposed to examine stomach contents of these extra fish and determine diet patterns. During this reporting period, stomach contents of these fish were examined and preliminary analysis of adult fish (greater than 350 mm) is given in Table 3. Diet was highly variable, but several aspects of the diet analysis are noteworthy. In fish from all areas except Georgian Bay, *Dreissena* (both zebra and quagga mussels), comprised a considerable portion of whitefish diet. On the other hand, *Diporeia* was found in the diet of fish from only one area (OMNR-8). Historically, *Diporeia* comprised up to 81 percent of whitefish diet in Lake Huron (Ihssen et al, 1981). These diet changes likely reflect the recent decline of *Diporeia* and the expansion of *Dreissena* populations in nearshore regions of the lake (Nalepa et al,

2003). Since *Diporeia* is rich in lipids and calories compared to *Dreissena*, trends in these two organisms are likely a major factor in the general decline of whitefish condition in the lake (Lloyd Mohr, OMNR, personal communication). Also, note the presence of *Hexagenia* in the diet of whitefish from Cape Rich (Table 3). *Hexagenia* is abundant in this portion of Georgian Bay (see Table 1).

Taxa or Group	MDNR (n=58)	USFWS (n=17)	OMNR-5 Southhampton to Chief's Pt. (n=39)	OMNR-8 Bayfield to Goderich (n=11)	OMNR-19 Cape Rich, Georgian Bay (n= 6)
Diporeia	0.0	0.0	0.0	22.0	0.0
Dreissena	21.9	70.1	18.0	55.0	0.0
Gastropoda	45.2	16.4	39.0	0.0	7.0
Sphaeriidae	21.7	0.0	0.0	0.0	0.0
Chironomidae	5.8	1.5	0.0	0.0	0.0
Hexagenia	0.0	0.0	0.0	0.0	20.0
Fish	3.3	12.6	21.0	0.0	0.0
Zooplankton	0.0	0.0	16.0	23.0	70.0
Other	2.0	0.0	6.0	0.0	4.0

Table 3. Diet of adult lake whitefish (greater than 350 mm) in various locations in Lake Huron. The MDNR and USFWS fish were collected along the Michigan shoreline from Alpena to the Straits of Mackinac, and the OMNR fish were collected along the Canadian shoreline at the location given. Values are the mean percentage wet weight. n = number of fish examined.

Future Activities

A major benthic survey was completed for the main basin of Lake Huron in August 2003. All 66 sites sampled in 2000 were re-sampled along with an additional 16 sites that were not sampled in 2000. These additional sites are located in areas where whitefish were collected by collaborative agencies in 2002. The main purpose of the benthic survey is to determine the rate of *Diporeia* decline throughout the main basin from 2000 through 2003. Over the next six months, CILER research assistant Andrew Foley will be spending most of his time counting D*iporeia* in these samples. We expect to again receive whitefish for diet analysis from MDNR, USFWS, and OMNR. With two years of data, we will then proceed to examine whitefish condition relative to diet in the various lake areas.

Publications

Price, H., S.A. Pothoven, M.J. McCormick, P.C. Jensen and G.L. Fahnenstiel. 2003. Temperature influence on commercial Lake Whitefish harvest in eastern Lake Michigan. *Journal of Great Lakes Research* 29(2): 296-300.

CA4/IV-10: Inventories of PCBs in the Depositional Sediments of Lake Michigan

Principal Investigators: Brian J. Eadie, Great Lakes Environmental Research Laboratory and John A. Robbins, Great Lakes Environmental Research Laboratory

Background

In aquatic systems, rapid and efficient sorption and settling remove contaminants from the water column into the sediments. Large episodic events resuspend and transport materials from temporary sedimentary sinks to more permanent sinks with a small fraction becoming incorporated annually into the sediments of the depositional basins. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades presently results in much greater fluxes to the water column than from all external inputs. The focus of this effort is to measure inventories of PCBs in Lake Michigan sediments and use these data in lake-scale mass balance models.

Research Plan

Between 1994 and 1996 a total of 55 sediment box cores were collected from the depositional regions of Lake Michigan. Subcores from each of the box cores were sectioned in 1 cm intervals to allow a detailed geochronology of sediment deposition. The vast majority of chemical analyses have been completed on these samples, including ^{137}Cs, ^{210}Pb (geochronology), and *surface* concentrations of organic carbon, carbonate, nitrogen, phosphorus, silica, PCBs, PAHs, and some pesticides. A subset has also been analyzed for the suite of elements measured by neutron activation analysis. The data are in near final form, needing some minor editing to improve ease-of-use and a small number of reruns for values that fail various QA/QC checks.

At each coring site, a low-resolution core was collected for possible later analyses of contaminant inventories. Each of these low-resolution cores had a high-resolution companion from the same box core that has been analyzed and its geochronology established.

In this project, Sander Robinson, a CILER research associate, will use the geochronological information to determine the depth position of the 1900-1920 horizon. All sectioned core samples from above that horizon will be carefully composited to create a single sample from each site that represents all sediments deposited from 1900-1920 through the mid 1990s – the entire period of loading for PCBs (marketed by Monsanto from 1930-1977). Each composite sample will be extracted and analyzed for congenor-specific PCBs. A careful interpretation of these data will allow us to calculate the total amount of PCBs stored in Lake Michigan and the patterns of their deposition will provide information on their sources and transport. Figure 1 illustrates the locations of all sediment samples collected; we will focus on box cores where PCBs are accumulating.

Activities

Compositing of the samples has been completed and laboratory analyses of congenor-specific PCB concentrations are ongoing. The results will be used by

several program collaborators in their calculations of the cycling of PCB, and other constituents within Lake Michigan. Our results will be published and provide best ever estimates of inventories of PCBs in Lake Michigan as well as being used to constrain mass balance and sediment transport models.

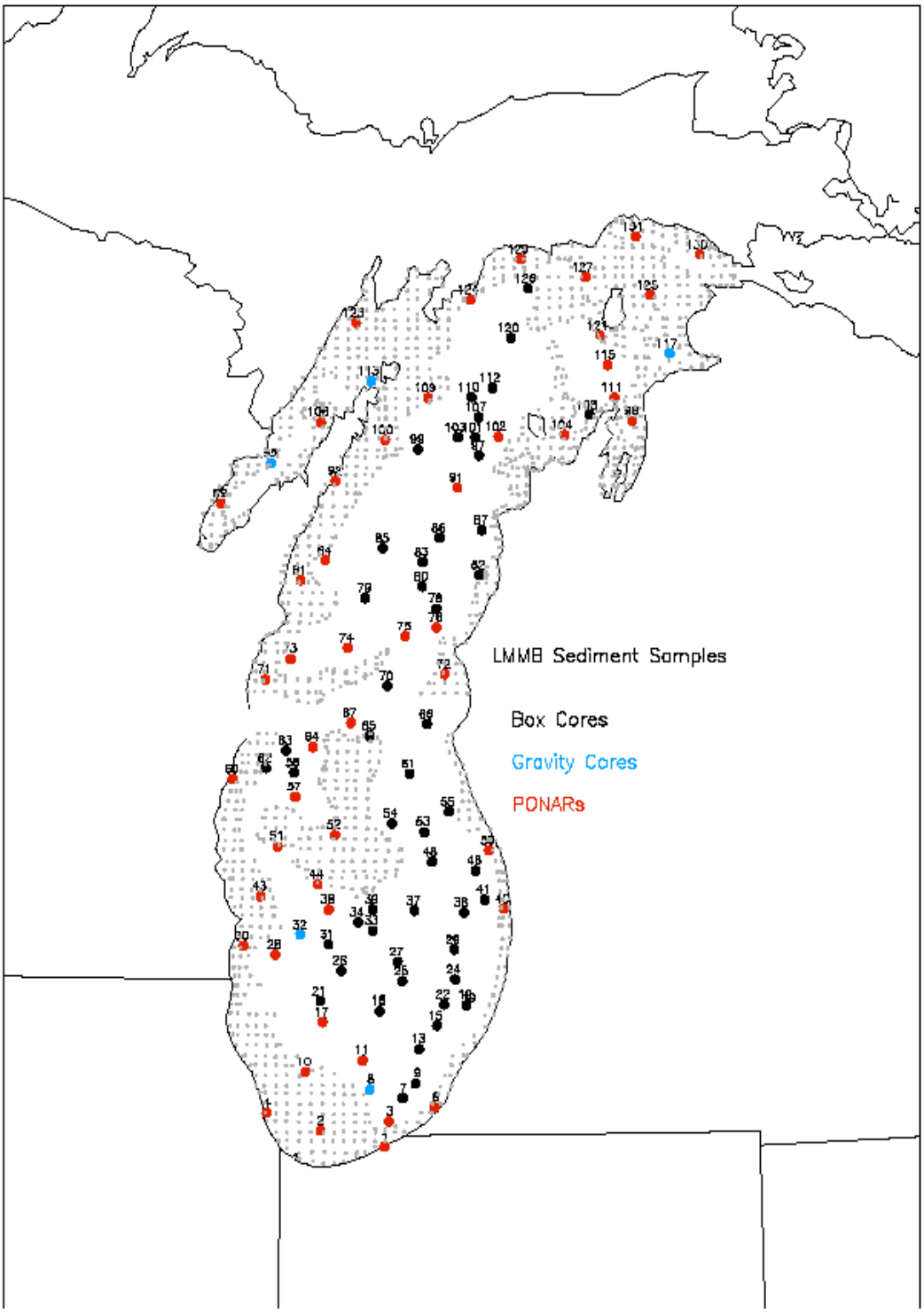

Figure 1. Illustration of locations where sediments were collected, with focus on PCB accumulation at box cores sites.

REMOTE SENSING OF LARGE LAKE AND COASTAL OCEAN DYNAMICS

Research by CILER Fellows in the area of remote sensing and coastal ocean dynamics builds upon an enormous base of expertise existing within the Great Lakes basin. In addition, large lakes and coastal oceans offer unique opportunities to further the science of remote sensing of surface and near surface dynamics. In the case of large lakes, remote sensing of the temperature field provides a direct measure of the density field. Hence, this one-to-one correspondence, which does not exist in the salt-water environment, provides new and exciting clues to the interrelations between physical, biological, and chemical processes. Remotely sensed environmental data for near real-time observation of the Great Lakes support a variety of research activities and resource management needs. For example, the rapid formation and extensive existence of ice throughout the Great Lakes basin creates a serious need to more fully utilize the capabilities of remote sensing to foster and promote safe navigation. Furthermore, the well-developed methods of terrestrial remote sensing provide excellent mechanism from which to analyze change brought about by society, environmental conditions, and land-water interactions. These capabilities utilized in a data fusion framework will provide the catalyst for the formation of the next generation of numerical predictive models for Great Lakes and coastal ocean dynamics.

CA4/V-01: Development of a Retrospective Near-Earth Space Environment Data Assimulation Tool

Principal Investigator: Aaron Ridley, University of Michigan

Overview

Year One. This project is an ongoing project that had year one funded through CILER cooperative agreement NA67RJ0148. In year one, there were a number of areas of research on this project:

- The investigation of low-latitude electric fields. These have been accomplished through the use of the University of Michigan's Ring-Current Atmosphere Interaction Model (RAM). We have combined this model with an electric potential solver, to determine the electric potential patterns caused by the asymmetric ring current.
- We have begun to rewrite the assimative mapping of ionospheric electrodynamics (AMIE) technique to allow different (more compact) data formats and to be easier to use. The new AMIE is written to FORTRAN 90 standards and has been run on various platforms. In addition, it has been parallelized using the Message Passing Interface (MPI).
- Some validation and sensitivity testing has been started on AMIE. This has been in the form of investigating the data sparseness on the solution, and attempting to quantify the effects of changing the internal data weighting system on the solution.

- We have begun to collect a large database of magnetometer data for the retrospective AMIE runs. We have focused on collecting and processing one year's worth of data (1997) to determine how automated the technique can be. From this, we have determined one-minute auroral electrojet index values for the entire year, which are not publicly available yet.

Year Two. We have continued to follow the lines of study outlined above, including:

- We have created a self-consistent version of the RAM code. This version calculated the field-aligned currents from the gradient in pressure in the inner magnetosphere, calculates the electric potential in the ionosphere, and maps that potential out to the magnetosphere. This potential is then used to move particles for the next iteration.
- The rewrite of AMIE is mostly complete. We have added the capability of reading in SuperDARN data files in the native format, such that no processing is needed to run AMIE on them. We have tested AMIE on a cluster of workstations and commonly run AMIE on 8016 processors. Dr. Gan Lu provided some routines for reading and using field aligned current data and electric field data. We still need to work out some good way of using global conductance images from POLAR or IMAGE in the inversion. These can be used, but the reading routines are not as optimal as they could be.
- We have continued to work on the validation of the AMIE technique. We have started to compare AMIE derived particle precipitation estimates with those measured by the DMSP J4 instrument. Much though has been done on what the best way to conduct a statistical validation. We have processed all of the DMSP J4 data for 1997 and 1998 and are waiting for the AMIE runs to be completed so we can do a large-scale, statistical validation of AMIE.
- We have continued to collect and process magnetometer data for the years of 1997 and 1998. We have run into roadblocks relating to the despiking of the data and the quiet day removal which took much longer to resolve than was expected. At this time, all 1997 and 1998 magnetometer data (approximately 150 stations) has been cleaned and has had the quiet day removed. An undergraduate is currently working on conducting AMIE runs for 1998, which will have as a by-product the AE and Dst indices for that year. We expect to make these publicly available shortly.
- The web interface for real-time (rtAMIE) has been cleaned up and an interface for getting old rtAMIE runs has been added. This allows users to have a 'quick look' at the ionospheric conditions for anytime in the last approximately six months.
- We have run four storms through the RAM model and have calculated the strength and location of the penetration electric field which is driven by the asymmetric ring current. We have used these calculations to come up with an imperical model of the low latitude electric field based on Dst, which is currently available in real time (see below).
- We have made AE, Dst, cross polar cap potential, hemispheric power, and total joule heating available to the community in real time.

- In order to get Dst in real time, we have collaborated with the 210 magnetic meridian magnetometer people to get approximately eight low latitude stations in real time.
- We have started work on the saturation of the cross polar cap potential by reading literature and becoming involved in the community debate on when the ionospheric potential starts to saturate (see publications below).
- We have provided AMIE runs for community members for different events, such as to James Burch, Thomas Immel, and Michael Liemohn.

Scientific Discoveries

We have made a number of different scientific discoveries within this project, namely:

Year One. It was found that the storm time ring current is capable of producing an anomalous electric field in the subauroral ionosphere and near-Earth magnetosphere. This electric field is caused by the closure of the asymmetric ring current, which is dominant during the main and early recovery phases of geomagnetic storms and persistent throughout the late recovery phase (although at a much reduced intensity). The modeled storm time electric fields are very consistent with observed electric fields in the midlatitude ionosphere and inner magnetosphere. They are also morphologically comparable with asymmetric ring current generated electric fields from the RCM, which includes the feedback of such fields on the hot ion populations. These electric fields will have serious ramifications for space weather, particularly ionospheric scintillation and plasmaspheric reconfigurations (affecting GPS signals, for instance). To pramaterize the magnitude of this low-latitude storm time electric field, a relationship has been derived between the cross polar cap potential and the Dst index. Training of this prediction algorithm on two of the studied storm intervals yields a formulation that accurately reproduces the time sequence of CPCP values for the other two storms. This relation can be used as an initial approximation of the CPCP for inclusion in space weather prediction schemes.

We have been investigating the sensitivity of AMIE on the location of the data, which is being ingested. This research has been focusing on ground-based magnetometers, but is mostly likely applicable to any data input into AMIE (although this has not been shown). It has been found that the root mean squared (RMS) error between the simulated and actual ground-based magnetic perturbations decreases by a factor of two if there is a single station located within the vicinity of the modeled chain of magnetometers. For example, if the magnetometer at Sondrestrom, Greenland is included in the inversion, the entire Greenland chain is modeled better. This is a qualitative assessment at this time, but we are working on quantifying the relationship between the data placement and the RMS errors.

While rewriting AMIE, we noticed that there are a large number of internal weighting factors on the data sets. These weighting appear to have a huge effect on the solution, so we have been working on quantifying the effect.

Year Two. While comparing the AMIE predictions of the electron energy input into the ionosphere to the DMSP J4 measurements, we have found that the

background model plays a significant role, since the data is quite sparse right at the peak in the auroral oval. The comparisons (for May 1998) indicate that the predicted auroral energy input is typically a factor of two lower than that measured by DMSP. When the peak auroral energy input is increased by a factor of two in the background model, the agreement increases. We have also found that the Ahn 1998 formulation for converting ground-based magnetic perturbations into auroral particle precipitation works better in some regions that the Ahn 1991 formulation, while the inverse is true in other regions. We have started to use the more accurate formulation in the different regions.

We have compared runs of AMIE with magnetometers only and runs of AMIE using SuperDARN data only. These are quite interesting and show that at times there may be a strong disconnect between the F-region ionosphere and the E-region ionosphere, or that the hall conductance may be extremely suppressed at times compared to the Pedersen conductance. We are working with SuperDARN people to attempt to determine what is causing this difference, and will eventually publish a paper on the different events. The comparisons are available over the web at http://butch.engin.umich.edu/amie/output/.

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Significant Interactions

From April 13 – May 12, 2002, Dr. Ridley visited the World Data Center in Boulder, Colorado. The purpose of this trip was to discuss and work on the project with the head of the project, Dr. Eric Kihn. During this time, a significant amount of progress was made on the research described above.

Dr. Eric Kihn visited the University of Michigan for five days. While here, we discussed implementation plans and progress which has been made on the project.

Additional Funding

Dr. Aaron Ridley has received an award from the National Science Foundation for a three-year project of approximately $65K per year. This grant is focused on much of the same tasks that were discussed in the initial NOAA proposal, but were cut back due to budgetary constraints.

CA4/V-02: CoastWatch Operations

Principal Investigator: George A. Leshkevich, Great Lakes Environmental Research Laboratory

CoastWatch is a nationwide National Oceanic and Atmospheric Administration (NOAA) program, within which, the Great Lakes Environmental Research Laboratory (GLERL) and CILER function as the Great Lakes regional node. In this capacity, GLERL and CILER obtain, produce, and deliver environmental data and products for near real-time observation of the Great Lakes to support environmental science, decision making, and Great Lakes research activities. These benefits are achieved by providing Internet access to near real-time and retrospective satellite observations, *in situ* Great Lakes data, and derived products to federal, state, and local agencies, academic institutions, and the public via the Great Lakes CoastWatch web site http://coastwatch.glerl.noaa.gov. The goals and objectives of the Coast-

Watch Great Lakes Program directly support NOAA's statutory responsibilities in estuarine and marine science, living marine resource protection, and ecosystem monitoring and management. Great Lakes CoastWatch data are used in a variety of ways including monitoring of algal blooms, plumes, ice cover, and water temperatures, two and three dimensional modeling of Great Lakes physical parameters such as wave height and currents, damage assessment modeling, research, and for educational and recreational activities.

Utilities such as JAVA based interactive retrieval of physical parameters such as surface temperature, ice cover, winds, and bottom depth at a given location enhance the accessibility and utility of Great Lakes CoastWatch data. A new image product, GOES SST, has recently been added to the suite of products. The images are derived from the Geostationary Operational Environmental Satellite (GOES) and represent a three hourly composite of water surface temperature at a 4-km resolution. In addition, a new image viewer and analysis utility (CDAT- CoastWatch Data Analysis Tool) for CoastWatch and other images has been made available on the Great Lakes CoastWatch website. Windows and UNIX versions are available for download.

This project focuses on research and applications development utilizing CoastWatch imagery and imagery from new satellite sensors such as synthetic aperture radar (SAR) for ice classification and mapping. In addition, ocean color sensors such as the Sea Viewing Wide Field-of-View Sensor (SeaWiFS) are used to produce ocean color (chlorophyll) products. These products will enhance the CoastWatch Great Lakes product suite by developing regional products and applications for the Great lakes, and will contribute to the operational responsibilities of agencies such as the US Coast Guard and the National Weather Service.

Accomplishments

Research collaborations conducted under this project have led to the development of the following Great Lakes regional remote sensing projects:

- Great Lakes Surface Environmental Analysis (GLSEA) – daily composite (5 day running mean) cloud free water surface temperature chart with ice cover overlay during the winter season derived from the National Ice Center Great Lakes Ice Analysis Charts.
- Reflectance (Turbidity) Product – This product is derived from Ch. 1 and Ch. 2 AVHRR data. Used for detection/monitoring of plumes and blooms.
- Histogram Equalized Ch.1 – This product is derived from Ch. 1 AVHRR data. Used for better ice detection.
- Statistics - This product (derived from the GLSEA) compares average lake-wide surface temperatures for a lake for period of record or for all lakes for a particular year (for period of record).
- Animations – this product provides animations (last 365 day and calendar year) of the temperature cycle on the Great Lakes derived from the GLSEA.
- RADARSAT SAR - imagery (subset by Lake)

- NOAAPORT- near real-time in situ meteorological data from buoys, CMAN, shore, and ship reports. This data helps in the interpretation of the remotely sensed data.
- Nowcast Winds – produced by the Great Lakes Coastal Forecasting System.

Additional Great Lakes regional satellite products under development include:

- Scatterometer Winds – for the Great Lakes derived from QuikSCAT.
- Scatterometer Ice Mapping – for the Great Lakes derived from QuikSCAT
- SAR Ice Classification – for the Great Lakes derived from RADARSAT / ENVISAT.
- Chlorophyll – for the Great Lakes derived from SeaWiFS / MODIS.

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Significant Interactions

On the Great Lakes CoastWatch web site http://coastwatch.glerl.noaa.gov users register for access to CoastWatch near real-time AVHRR satellite image data via an interactive electronic form which, upon submission, instantaneously sends a username and password back to the user. The user information is extracted from the electronic online registration form file by a perl program and imported into a Microsoft Access database. During the period July 1, 2001 through June 30, 2003, 508 users have registered for access to near real-time AVHRR imagery. The Great Lakes Node currently has a total of 1,416 registered users.

Additional Funding

Funding for the CoastWatch related satellite SAR (Synthetic Aperture Radar) and ocean color projects are provided by NOAA/NESDIS and COP (Coastal Ocean Program).

MARINE ENVIRONMENTAL ENGINEERING

The Great Lakes and coastal waterways of the United States have been threatened in recent times by many invasive (non-indigenous) species. The primary mode of introduction and transport of these foreign invaders resides in marine vehicles, structures and systems, associated with the water-bore segment of world trade. In addition, mechanisms for the handling of contaminated sediments, dredge spoils as well as accurate and automated methods of providing safe navigation are expected to provide many difficult technical problems related to the marine environment. As new problems are discovered, innovative and revolutionary marine environmental engineering solutions will be required. Research by CILER Fellows in this task includes engineering related to the design and production of a wide variety of vehicles, structures, and systems to operate successfully in the harsh and demanding marine environment and also includes engineering which supports the understanding and proper use of the marine environment.

CA4/VI-01: Disinfection of Ballast Water with Chemical Disinfectants

Co-Principal Investigators: Peter F. Landrum, Great Lakes Environmental Research Laboratory

The release of ballast water from foreign vessels is a major vector for the introduction of invasive nonindigenous species into the Laurentian Great Lakes. This project evaluated the potential effectiveness of three different biocides, Disinfekt 1000® (glutaraldehyde plus a proprietary quaternary ammonium surfactant), SeaKleen™ (menadione and menadione metabisulfite 2:8), and hypochlorite (NaOCl) for reducing the number of viable organisms potentially released from foreign NOBOB (no-ballast-on-board) vessels. Four primary objectives were identified:

- To establish the relative potency of glutaraldehyde with adjuvant (surfactant) compared to calcium (sodium) hypochlorite.
- To establish a concentration of hypochlorite and glutaraldehyde with adjuvant that is effective in the presence of sediments
- To demonstrate the effectiveness of biocide treatment of ballast water.
- To demonstrate the degradation of the biocide with dilution with local water. (The testing of SeaKleen™ was not part of the original proposal but was added late in the study because it is being developed as a potential ballast water disinfectant and will enhance the study to compare its effectiveness against the original compounds under study.)

Results

Disinfekt 1000®, measured as amount of glutaraldehyde, was more effective at killing both *Lumbriculus variegatus* and *Hyalella azteca* under water-only conditions than glutaraldehyde alone. For *L. variegatus*, the LC90 value for Disinfekt 1000® is

7.6 mg L^{-1} (95 percent C.I. 6.8-13.2) and for *H. azteca* the LC90 is 272 mg L^{-1} (95 percent C.I. 243-328).

Hypochlorite and SeaKleen™ exhibited similar levels of toxicity among organisms tested in common for aqueous exposures (no sediments or suspended sediments). Disinfekt 1000® was somewhat less toxic for the *L. variegatus* and was substantially less toxic for *H. azteca.* Both SeaKleen™ and Disinfekt 1000® are non-oxidative materials and would not be expected to cause corrosion problems when used in ballast tanks. The concentration that would likely be required for these two compounds to serve as disinfectants in the absence of bedded sediment or suspended sediment particles would be about 250 mg L^{-1} for Disinfekt 1000® and 3 mg L^{-1} for SeaKleen™. In contract, hypochlorite is an oxidative material, and the levels required for 90 percent mortality in the absence of sediment would be as high as 130 mg L^{-1} for *Dreissena polymorpha,* and might lead to corrosion problems. The most sensitive species tested in water-only exposures were algae for both Disinfekt 1000® and hypochlorite, requiring less than 1 mg L^{-1} to inhibit growth. These data provide an indication of the levels that might need to be achieved prior to the discharge of treated ballast. Finally, resting stages, *Artemia* cysts, were tested for hatching success and exhibited comparable toxicity values to the most resistant of the other species tested with Disinfekt 1000® or hypochlorite.

Using a 4:1 water:sediment ratio with Gallup Park sediments and comparing across compounds with *L. variegatus*, SeaKleen™ was the most toxic biocide requiring only 88 mg L^{-1}, followed closely by Disinfekt 1000® with an LC90 of 248 mg L^{-1}. Hypochlorite, because of its reactivity, was the least toxic in the presence of sediment and required the addition of over 3000 mg L^{-1} to produce 90 percent mortality. Further, the range of LC90 values for *L. variegatus* among different types of sediment ranged from 3000 to 25,000 mg L^{-1} due to differences in sediment composition, particularly the organic carbon content.

Degradation of hypochlorite was extremely rapid and was responsible for the large concentrations required in the presence of sediment to produce an LC90. Degradation occurred even in aqueous solution with half-life values as low as 13 min at low hypochlorite concentrations. The longer-term degradation half-lives of residuals ranged from 13 – 44 h in the presence of sediment. Disinfekt 1000® measured as glutaraldehyde showed degradation half-lives in the range of 5 to 15 d, with the fastest rates in the presence of sediment.

The ballast water simulation experiments indicated that the use of 250 mg L^{-1} for Disinfekt 1000® and 1000 mg L^{-1} for hypochlorite were adequate to eliminate the stocked target organisms. Further, there was no overt evidence of the hatching or growth of organisms from cysts following a 10 d grow out period after dilution with fresh water.

In conclusion, it is likely that sufficient disinfectant can be added to ballast tanks to address the disinfection of the water and sediment. However, the amount of hypochlorite may need to be large because of its reactivity to sediments and other materials in order to produce adequate effective residual. When NOBOB vessels are treated, the subsequent dilution of the residuals will allow dilution and degradation of the applied disinfectant to reduce the potential of discharging concentrations that may have effects in the environment. However, algae are very sensitive to these

biocides and local effects may occur despite the relatively rapid degradation of the compounds.

Presentations

Landrum, P.F. and L.L. Sano. 2003. Characterizing potential chemical disinfectants for use in ballast water. The Great Lakes: Managing and Understanding A System Under Change. Michigan State University and Michigan Department of Environmental Quality Office of the Great Lakes. March 6. East Lansing, Michigan.

Sano, L.L., P.F. Landrum, D.C. Gossiaux and M.A. Mapili. 2002. Comparison of biocide effectiveness in treating unballasted foreign vessels. The 23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry, North America. November 16-20. Salt Lake City, Utah.

Sano, L., P. Landrum and A. Krueger. 2001. Biocide treatment of ballast water: environmental effects. The 22nd Annual Meeting of the Society of Environmental Toxicology and Chemistry (North America). November 11-15. Baltimore, Maryland.

Sano, L., P. Landrum, R. Moll and A. Krueger. 2001. Biocide treatment of ballast water: efficacy. The 22nd Annual Meeting of the Society of Environmental Toxicology and Chemistry (North America). November 11-15. Baltimore, Maryland.

Significant Interactions

We have helped review experimental designs and reports for the Michigan Department of Environmental Quality for ballast water testing.

Student Participation

Mapili, Mark. 2003. "Acute Toxicity of DISINFECT 1000®:An Evaluation of a Biocidal Approach to Disinfecting Ballast Water." Masters of public health, School of Public Health, University of Michigan.

CA4/VI-02: Biological Characterization or Assessment of ANS Invasion Risk from NOBOB Vessels

Principal Investigators: Gary L. Fahnenstiel, Great Lakes Environmental Research Laboratory; Thomas H. Johengen, University of Michigan and David F. Reid, Great Lakes Environmental Research Laboratory.

Background

Global shipping moves roughly 80 percent of the world's commodities and is fundamental to world trade. As an unintended result of these shipping activities, numerous cases of nonindigenous species introductions have occurred worldwide. In total, 159 successful exotic species invasions have been documented in the Great Lakes, and 41 of these introductions are believed to have resulted from shipping activities. Furthermore, the rate of introductions has increased dramatically during

the past few decades, with six new introductions occurring between 1984 and 1990 alone. While we need not belabor here the widespread and deleterious effects of the zebra mussel, we note that less conspicuous introductions also can wreak ecological and economic havoc. For example, 23 phytoplankton species have been introduced to the Great Lakes via shipping activities and large populations of one of these, *Stephanodiscus binderanus*, have caused significant water quality (taste and odor) problems in municipal water treatment facilities. Moreover, successful introduction of non-indigenous phytoplankton into the Great Lakes has contributed to the extirpation of native species via competition, a result with ramifications for the base of the food web.

While circumstances vary from ship to ship, the relatively small amount of water that remains in most NOBOB (NO Ballast On Board) vessels entering the Great Lakes, together with any residual sediment, potentially harbors nonindigenous organisms. Consider a tank holding 1500 metric tonnes of water when full. If only one percent of that volume is unpumpable, then up to 15 metric tonnes of water would remain. Reflected across the numerous tanks each ship possesses, a significant tonnage of ballast water can remain on board. Indeed, a 1991 Canadian study of NOBOB vessels entering the seaway reported volumes of ballast residuals ranging from 59 to 468 tonnes, with an average of 158 tonnes. It is this phenomenon that makes critical our better understanding of NOBOB vessel operations on the Great Lakes. Concerns about NOBOB biopollution have risen from a position of relative obscurity a few years ago to one of the chief environmental concerns in the Great Lakes basin today. On average, less than 25 percent of the ocean vessels entering the Great Lakes contain declarable ballast water on board. In 1996, for example, of 538 ocean entries, only 38 (6.1 percent) were vessels "in ballast" and thus subject to ballast water exchange requirements. NOBOB vessels escape regulation under existing U.S. and Canadian federal, state, and provincial laws, yet their ballast tanks may retain residual volumes of unpumpable ballast water and may contain an accumulation of sediment representing numerous previous ballasting operations.

Rationale

Considering that NOBOB ships now constitute the bulk of commercial ship traffic entering the Great Lakes, we propose to examine the possibility of invasions associated with their residual ballast water and sediment. We will evaluate the risk of invasions associated with ocean-going vessels entering the Great Lakes. Specifically, two interrelated objectives will be addressed:

1. Characterize phytoplankton communities present in NOBOB tanks.
2. Measure the effect of adding Great Lakes water as ballast to NOBOB tanks on germination and growth of nonindigenous phytoplankton species present in ballast residuals and on their potential release from ballast tanks.

Accomplishments

Analyses of phytoplankton abundance and growth potential were completed for all samples collected in 2001 and 2002 including 55 wet sediment samples and two dry sediment samples. Dinoflagellate cyst represented zero to 80 percent of total

between phytoplankton abundance (average = 24 percent). Almost all the samples contained at least one dinoflagellate species, with a maximum 13 species. A total of 35 cysts species were identified, and 20 species were repeatedly found in both years. Twenty five percent of these species are reported to be toxic species, and a PSP causing species *Alexandrium minutum* is the most common species which occurring in 33 percent our samples. All the dinoflagellate cysts identified in our study are non-indigenous, including at least three species that are common members of the Baltic Sea flora. Dinoflagellate cyst species were found less in flushed tanks than in non-flushed tanks. Further study of the relationship between cyst composition and management practices may help to identify a protocol for monitoring the efficiency of management practice.

Germination and growth experiments were completed for samples collected in 2001 and 2002, including 33 water samples and 57 sediment samples. Experiments were performed using four different freshwater and one saltwater culture media. In all experiments at least one of the freshwater treatments produced phytoplankton growth from the residual material. However, there was tremendous variability in the growth potential of each sample among treatments, both in absolute response and the dominance of species.

Diatoms were the dominant species in almost all growth experiments. Twenty-five species of non-indigenous marine and freshwater diatoms have been identified from the 20001 samples. Germination of non-indigenous species was found in 50 percent of samples; most of these species (50 percent) can grow in Lake Michigan or Grand River water, indicating the potential for ballast tank residuals to be a source of viable non-indigenous phytoplankton species to the Great Lakes. Several non-indigenous species were found to grow in both freshwater and saltwater culture media, indicating their potential viability in ocean water exchange treatment.

The goal of objective 2 is to assess whether the biota (including resting stages) resident in ballast tank residual water and sediment can invade the Great Lakes under actual ship operating conditions. We assume that mature pelagic organisms from the residuals can and do become entrained in ballast water added in the Great Lakes and thus may be discharged.

A total of five different vessel voyages were examined for objective 2, one in each 2001 and 2002, and three in 2003. Germination experiments were completed for all of the samples from these voyages. Experiments were performed using freshwater culture medium (GL) and Lake Michigan water. Phytoplankton growth was minimum in Lake Michigan water, but growth was significant in GL medium. There was significant variability in the growth potential of samples collected from the harbor water where ships were ballasting and ballast samples taken at the initial and final time points of the voyages. Phytoplankton growth was significantly higher in final ballast samples than in the harbor water sample for the 2001 experiment. Furthermore, there were no marines species observed in the harbor and initial samples, but marine species accounted for about one percent in the final sample. For the 2002 trial, the growth of phytoplankton was similar between initial and final sampling time points. For the 2003 trials, growth was significantly different between harbor water, T_0 ballast sample, and T_f ballast sample. The species composition analysis from these trials is under process.

Presentations

Johengen, T.H., D.F. Reid, P.T. Jenkins, S.A. Bailey, C.D.A. van Overdijk and S.A. Constant. 2003. Assessment of NOBOB ballast tank residual as a potential vector of ANS: a summary of field activities and chemical conditions within the tanks. Joint International Association for Great Lakes Research/ International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Reid, D.F., S.A. Bailey, T.H. Johengen, S.A. Constant, P.T. Jenkins, C.D.A. van Overdijk, I.C. Duggan and H.J. MacIsaac, 2003. NOBOB project task 2: ballast tank mesocosm experiments and use of incubator-emergence traps. Joint International Association for Great Lakes Research/International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Hong, Y., G.L. Fahnenstiel and R. Stone R. 2003. Dinoflagellate cysts in NOBOB ballast tank sediment: potential risk of invasion to the Great Lakes. Joint International Association for Great Lakes Research/International Lake Environment Committee Conference. June 22-26. Chicago, Illinois.

Fahnenstiel, G. 2002. NOBOB vessels as vectors of non-indigenous phytoplankton in the Great Lakes. Winter ASLO Meeting. February 11-15. Honolulu, Hawaii.

Significant Interactions

This project was funded by multiple sponsors that included the U.S. Coast Guard, NOAA, and U.S. EPA. In addition, the activities conducted within this project led to the development of a successfully funded research proposal submitted to the Great Lakes Protection Fund. These additional funds allowed us to extend the scope of work, increase the number of vessels sampled, and increase the breadth of analyses conducted on ballast tank residuals. This project involves the collaboration of researchers from GLERL, the University of Michigan, the University of Windsor, and Old Dominion University. Results described here represent activities completed under the supplemental project as well as the cooperative agreement project.

CA4/VI-03: Application of Passive Acoustic Methods for Automatic Detection of Right Whales: Numbers and Distributions.

Principal Investigator: Christopher W. Clark, Cornell University

Background and Rationale

The population of northern right whales in the western North Atlantic is highly endangered. Ship strikes and fishing gear entanglements have lead to an increase in mortality. There is a critical need to monitor the number and distribution of whales throughout the year over large areas of their habitat. Efforts to survey right whales rely primarily on visual sightings of animals from vessels or aircraft. Photo identification and molecular genetic techniques have also advanced our understandings of calving rate, site fidelity, and population structure. Despite significant progress, the distribution of over half the right whale population is unknown for more than half the year. The primary reason for this large uncertainty

is due to the limited capabilities of present methods to sample for right whales for long periods of time over large portions of their habitat. This sampling limitation is a result of the fact that all present methods rely on detecting whales when they are at the surface and visible to human observers. Therefore, a sampling method that is independent of visibility conditions and does not require animals to be at the surface could dramatically increase right whale detections and improve survey effectiveness.

Right whales produce distinctive sounds throughout the year. There is good evidence to support the assumption that passive acoustic methods can provide an effective mechanism for detecting and estimating the number of right whales (Clark 1982; 1983; Kraus 1991). Preliminary results from 2000 in Great South Channel and 2001 in Cape Cod Bay are very encouraging and indicate that the numbers and distributions of whales from acoustic detections were in general agreement with results from the aerial surveys (Clark et al. 2000). Furthermore, preliminary results suggest that the probability of hearing a right whale call is very high if one listens for at least four hours and there is a right whale in the area. For Cape Cod Bay in 2001, over 40,000 right whale calls were detected in 25 days at three acoustic sampling stations, an average of over 260 calls/day/station.

Beginning in mid-December 2001 and continuing into early June 2002, with funding from the Northeast Consortium (NEC) program, Cornell Bioacoustics will deploy a total of 12 autonomous seafloor acoustic recorders in Cape Cod Bay (n=6) and across portions of the Great South Channel (n=6). These units, referred to as "pop-ups", will each record continuously for periods of two to three months. There will be two deployments in each area to provide coverage from early winter through late spring. Detections of right whale sounds are determined after the units are recovered and will be used to estimate whale numbers and distributions. In cases where three or more units are deployed in a geometric array, vocal right whales will be located and tracked. To specifically quantify and evaluate the relationship between acoustic detections and aerial survey sightings and the relationship between whale numbers and distributions and oceanographic variables we are collaborating with Drs. Brown and Mayo from the Center for Coastal Studies. The Cape Cod Bay and Great South Channel research includes collaborations with the Center for Coastal Studies (CCS) and the International Fund for Animal Welfare (IFAW), and a cooperative working relationship with the Massachusetts Division of Marine Fisheries (Dan McKiernan) and the Northeast Fisheries Science Center of the National Marine Fisheries Service (NMFS-NEFSC).

Additionally, in a pilot collaborative study with the Gulf of Maine Ocean Observing System project (GoMOOS), we will install an automatic real-time right whale detection system on one of the GoMOOS fixed buoys. By this process, counts of right whale calls will be relayed to shore stations and linked to a the GoMOOS website (http://www.gomoos.org) on an hourly basis, making it possible for viewers to receive simultaneous information on physical and biological oceanographic conditions as well as right whale acoustic activity.

The present pop-up scheme provides adequate spatial sampling during the December through June period. Because present plans are for only six pop-ups in Cape Cod Bay, we cannot fully cover the entire Cape Cod Bay (CCB) region. Likewise, because present plans are for only six pop-ups in Great South Channel (GSC), we can only install a single detection net across the region.

Pop-Up Acoustic Recorder Technology

Based on the success of the various seafloor acoustic recorders developed by ocean engineers, we designed and fabricated our own units, which we refer to as "pop-ups". These units[1] have now been used successfully in ocean depths ranging from 25 to 2200 m for durations of five to 40 days, on blue, fin, humpback, bowhead and right whales. In the past two years, through various collaborations, we have had over 100 successful deployments of pop-ups.

The present generation of pop-ups can be deployed for periods of up to 65 to 70 days. The limiting factor on deployment length is battery life. The pilot project with GoMOOS in winter 2002 is a preliminary step in the process of developing smarter real-time right whale detection systems. A critical need is to design the next generation of pop-ups, which would allow deployments of up to a full year. These "smart" pop-ups would use new low-power, high-speed processors to run the signal detection software in real time and would save only those sounds that are the whale sounds of interest. By linking the detection results with telemetry systems, acoustic data on right whale presence and relative numbers could be available on a timely basis. The acoustic record would also provide information on ambient noise conditions and the presence or absence of vessel activities.

Increased Spatial and Temporal Sampling

As described by Clapham (1999) and by the IWC (IWC 2000) the general characteristics of the right whale population distribution are known, but major gaps exist. As summarized in Clapham (1999), "The whereabouts of significant portions of the population are unknown for virtually all months of the year. Furthermore, recent genetic and sighting data indicate that, while many mature females consistently take their calves to the Bay of Fundy during the summer, a significant number do not."

Pop-ups offer a cost-effective and reliable mechanism for long-term monitoring of areas that are more difficult to sample. We will use Cornell's new research vessel operating out of the Isles of Shoals and also collaborate with IFAW, CCS, and the Massachusetts Division of Marine Fisheries (Dan McKiernan) for deployment and retrieval of these recorders.

Activities

This project provided additional funding to augment and extend ongoing research funded through the NEC program. The specific objectives of the research are to apply passive acoustic methods to:

- Sample for the presence of right whales.

[1] A pop-up includes a programmable microprocessor, acoustic communications circuitry, a hard disk for data storage and batteries, all sealed in a single 17-inch glass sphere. An external hydrophone is connected to the internal electronics through a waterproof connector. Sound received by the hydrophone is digitized and stored on the hard disk. Recording can be continuous, or on any schedule programmed into the cpu. While a pop-up is deployed on the seafloor, an operator can communicate with it from a surface vessel via an acoustic transponder system. Using the transponder, the operator can query the pop-up about its operating status or command the unit to release its anchor and return to the surface for retrieval.

- Estimate the relative number of animals.
- Estimate the relative distribution of animals within several critical right whale habitats in waters around New England.

Validation of the passive acoustic method is being examined by statistical comparisons of acoustic results with those from visual surveys. These acoustic and visual results will also be integrated with physical and biological oceanographic data from surveys and remote sensing systems. These multiple data sets will be used to evaluate relationships between the number of whale calls detected, the number of whales seen, and oceanographic productivity when averaged over various time periods ranging from days to weeks.

In this project we emphasize that a multidisciplinary approach is the most effective means of elucidating the fundamental mechanisms underlying right whale distribution and fecundity, and therefore of implementing an effective conservation management policy. Present methods for monitoring right whales and estimating relative numbers over large portions of their habitat for long periods of time are inadequate. We are developing a passive acoustic research program to extend spatial and temporal sampling for right whales and as a means of developing a time-efficient mechanism for estimating right whale number and distribution in the northeast region of the North Atlantic.

In several workshops the suggestion has been made that passive acoustics could be used as a mechanism for an early warning system. We are convinced that passive acoustic detection of right whale sounds can be automated. The implementation of an early warning system would require a buoy equipped with a telemetry mechanism for transmitting data back to shore in real time. The recent Gulf of Maine Ocean Observing System (GoMOOS) project has installed a suite of moored buoys throughout the GoM region. With support from the NEC, Cornell is collaborating with the GoMOOS project to install a customized right whale acoustic detection units on one of the GoMOOS buoys. This buoy will deliver hourly right whale sound counts using onboard real-time detection technology and will store all acoustic detections on a resident hard drive. Detection count data will be telemetered back to the GoMOOS web site and made available on a near-real-time basis. Specific research activities for the project include:

- Deploy ten pop-ups in Cape Cod Bay from April 2002 through August 2002. These additional units will allow us to fully cover the Cape Cod Bay region so that acoustic and aerial coverage areas are essentially identical throughout the period when right whales are expected in the Bay. Units will be deployed in two arrays with four pop-ups per array (total of eight) and two separate units across the mouth of the Bay to the west of Race Point.
- Deploy ten pop-ups in Great South Channel from April through September 2002. This extra effort will nearly double the coverage in the Great South Channel. Pop-ups will be deployed in two east-west lines covering the northern and southern portions of the region, with units separated by about ten miles, thereby creating two east-west acoustic "nets."

CA4/VI-04: Assessing Ecological Risks Posed by a Ballast Water Disinfectant

Principal Investigator: Peter F. Landrum, Great Lakes Environmental Research Laboratory

Rationale

The release of nonindigenous species into the Great Lakes via ballast water poses a continuing threat to this ecosystem. One option for reducing the number of viable organisms released from transoceanic vessels is the application of chemical disinfectants (or "biocides"). This treatment approach may be most effective for vessels classified as NOBOB (no ballast on board), which constitute the majority of transoceanic vessels arriving into the Great Lakes. Biocide treatment of NOBOBs has potential because these vessels contain relatively small amounts of ballast material and undergo cross-transfer of lake water into ballast tanks, which dilutes the amount of biocide and increases the potential for degradation prior to discharge of treated ballast water. One of the major drawbacks of biocide treatment, however, is the potential for ecological impacts following release of biocide residuals into receiving waters. For many of the biocides considered for ballast water treatment, acute toxicity may result from the release of high concentrations of the biocide, but using low concentrations may have minimal impact as a treatment procedure. In addition, many of the impacts will likely be in port and harbor areas, many of which are already subject to other chemical stressors.

The objective of this work is to estimate and evaluate ecological risks posed by the discharge of glutaraldehyde from ship ballast tanks to surface waters of the port of Duluth, MN. This research will be accomplished via three primary modeling efforts:

- A model to characterize the degradation of glutaraldehyde in ballast tanks following initial application at overseas ports.
- A model to determine the dynamics of glutaraldehyde degradation and dilution in ships that reballast while navigating the Great Lakes.
- A model to translate glutaraldehyde releases into ecosystem-level impacts, by estimating the probable lethal and sublethal effects to selected local populations of aquatic producers, consumers, and decomposers.

Approach

Decay equation. To estimate the potential decay of glutaraldehyde in the tanks of NOBOB vessels, an equation was fit to data generated from previous water-sediment degradation experiments. These experiments were conducted at three different temperatures (25C, 15C, 5C), and at three different glutaraldehyde concentrations (500 mg L^{-1}, 100 mg L^{-1}, and 10 mg L^{-1}). The degradation data were fit to an equation that includes a first order decay function and a power function, which reflects nonlinear changes in glutaraldehyde concentration.

Trans-Atlantic Transit. To estimate the degree of decay during transit across the Atlantic, treatment of vessels was assumed to occur at Antwerp, Belgium. This port frequently serves as the port of origin for many transoceanic vessels that visit the Great Lakes (Colautti et al. 2003) and represents one of the shortest transit times from Europe to the Great Lakes making it a worst-case scenario. A great circle path was constructed for a hypothetical vessel transit from Antwerp to the entrance to the

Gulf of the St. Lawrence. Temperature data from the Comprehensive Ocean-Atmosphere Data Set (COADS, for the years of 1950-1992) of sea surface temperature observations were used to construct a temperature profile for the transit, given a great circle path. These data represent collections of surface marine data observations from a variety of platforms. The data have been "trimmed" using a procedure that identifies potential outliers based on the climatological 3.5 sigma limits derived from specified data periods. Based on the latitude/longitude data, the average monthly temperature for a specified segment of the great circle route was used. The weighted mean temperature of each segment was then estimated by dividing the average temperature by the time the vessel spent in each segment of the great circle. This was calculated assuming an average vessel speed of 14 knots (or 15.5 miles hr^{-1}). The sum of these weighted averages was then calculated in order to estimate the mean weighted temperature of the transit. This decay model was run using a random number generator to select hypothetical transit times across the Atlantic, ranging from 10 days to 14 days. The output of the model was then used to initialize a second model, to determine decay during transit through the Great Lakes.

Great Lakes Transit. The transition from the trans-Atlantic transit to the Great Lakes transit is assumed to occur as vessels enter the Gulf of St. Lawrence (around the Port-aux-Basques). For the Great Lakes transit segment, the temperature data were derived from individual moored buoys, maintained either by the Marine Environmental Data Service (MEDS), Canada Department of Fisheries and Oceans, or by the National Data Buoy Center (NDBC), National Oceanic and Atmospheric Administration (NOAA). For the MEDS buoys, any data points that were flagged as "doubtful," "erroneous," or "off position" were eliminated from analysis. In addition, some of the temperature readings when the buoy was first deployed at the start of the season were much higher than subsequent readings; thus the first day of temperature measurements were also discarded from analysis. The average temperature data for different julian days and for specific lakes were then calculated and used to parameterize the model.

This portion of the decay model was run assuming a worst-case reballasting scenario and a best-case reballasting scenario. The former scenario assumes that a vessel reballasts at the port of Windsor, Ontario. Because most decay occurs at lower concentrations of glutaraldehyde, this represents a conservative estimate of the maximum biocide residual concentration at Duluth, since less time elapses between reballasting and release. The best-case scenario involves reballasting at the port of Oswego, Ontario. This site is located on Lake Ontario, and permits more time between reballasting and release of biocide residual at Duluth.

Results

Data from degradation experiments were fit to obtain a first-order degradation equation that accounts for both changes in the initial glutaraldehyde concentration and the environmental temperature. The resulting equation indicates a high correspondence between modeled and observed laboratory results, across all three concentrations and temperatures. This correspondence is reflected in a high value for the goodness of fit parameter ($R^2 = 0.9985$).

The output from the trans-Atlantic decay model segment indicates that glutaraldehyde concentrations do not vary much based on month or length of transit. This result is attributed to the high value of the initial glutaraldehyde concentration (500 mg L^{-1}) and the low sea surface temperatures of the Atlantic, at the relevant latitudes. These conditions limit glutaraldehyde decay and are reflected in predicted concentrations at the Gulf of St. Lawrence, varying by only six percent, with the highest average predicted concentration occurring in April (462 mg glutaraldehyde L^{-1}) and the lowest average predicted concentration occurring in August (436 mg glutaraldehyde L^{-1}).

Preliminary output from the decay model for Great Lakes transits indicate that the concentration of glutaraldehyde residuals released at Duluth will depend primarily on the dilution factor associated with reballasting: Vessels that take on a large amount of water during reballasting operations will experience more dilution and a lower glutaraldehyde concentration, which facilitates degradation (Figure 1). The dilution effect causes an approximate 10-fold difference in the expected residuals released at Duluth. Other factors such as duration of transit, time of year, and port of reballasting have a more minor effect, varying residual concentrations by less than a factor of 2.

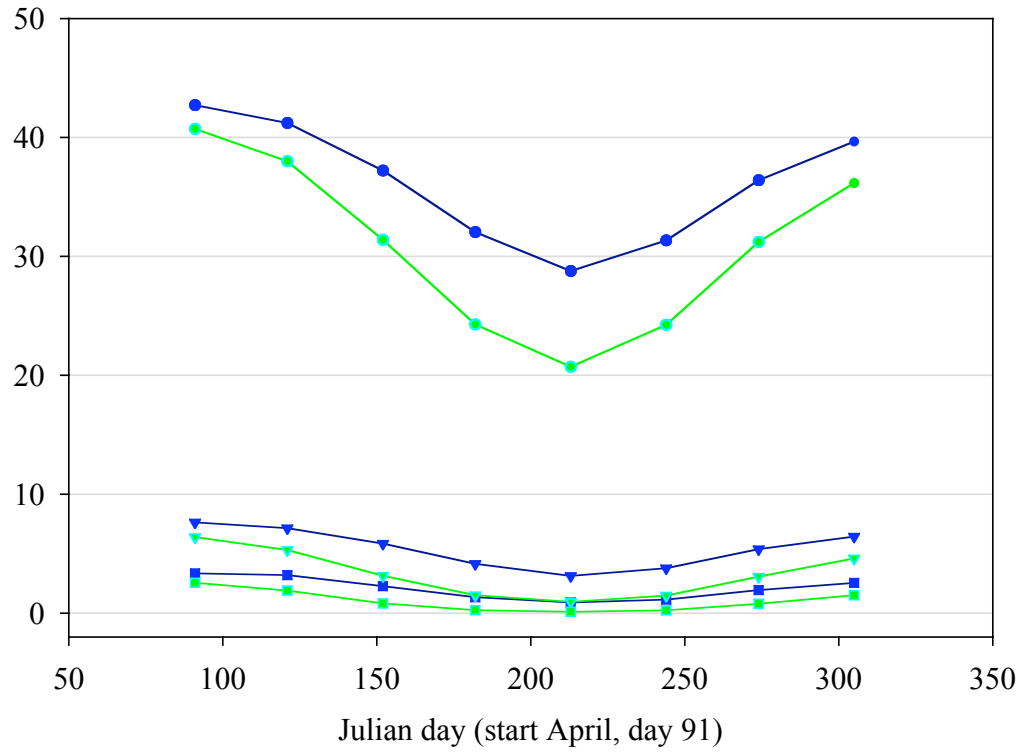

Figure 1. Predicted concentration of glutaraldehyde released at the Duluth-Superior Harbor. Data are presented for a worst case scenario (reballasting at Windsor) and a best case scenario (reballasting at Oswego). is 10-fold dilution, worst case scenario; ▼ is 50-fold dilution, worst case scenario; is 100-fold dilution, worst case scenario; is 10-fold dilution, worst case scenario; ▼ is 50-fold dilution, worst case scenario; and is 100-fold dilution, worst case scenario.

Future Directions

The next phase of the research is to estimate potential concentrations of glutaraldehyde after the compound is dispersed and advected from the slips where the ships deballast. These estimates will be employed to generate a concentration field of glutaraldehyde around the slip areas. The resulting concentrations will then seed an ecological effects model based on the comprehensive aquatic system model (CASM). This model is currently being revised to reflect the trophic relations in the Duluth Harbor.

Publications

Landrum, P.F., L.L. Sano, M.A. Mapili, E. Garcia, A.M. Krueger and R.A. Moll. 2003. Degradation of chemical biocides with application to ballast water treatment. NOAA Technical Memorandum GLERL-123. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan. 37 pp.